‘Island’ eradication within large landscapes: the remove and protect model

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Abstract New Zealand has been the world leader in the eradication of invasive mammalian predators from offshore islands. Today, the focus for invasive predator management is shifting to larger landscapes; big inhabited islands or the mainland itself. The most cost-effective approach in the long term will be to eradicate the predators from those areas, ensuring permanent freedom for vulnerable and threatened native biodiversity to recover or be reintroduced. Island eradication technologies cannot always be employed on the mainland (e.g. aerial brodifacoum), so a new approach is required. Zero Invasive Predators Ltd (ZIP) is a not-for-profit research and development entity, established in New Zealand through public, private, and philanthropic funding, to pioneer a novel predator management model for landscape-scale application – a model known as ‘Remove and Protect’. ZIP is developing the tools and technologies to both enable the complete removal of rats, possums, and stoats from large areas of mainland New Zealand, and then protect those areas from reinvasion. Among the innovations being tested is the ‘virtual barrier’, essentially converting large peninsulas into islands without the use of traditional predator fencing (which is expensive and impractical in some terrain); and a ‘minimal infrastructure’ detection system for automated early warning of any predator incursions. We review the transformative predator management model ZIP is developing and how it could help to pave the way towards large-scale predator-free landscapes.

Keywords: detection, invasive predators, mainland, *Rattus*, response, *Trichosurus vulpecula*, virtual barrier, 1080

INTRODUCTION / CONTEXT

New Zealand is a global biodiversity hotspot (Myers, et al., 2000), yet more than 3,000 native taxa are threatened or at risk of extinction (Hitchmough, 2013). It is generally agreed that there are three mammalian predator species that cause most of the ecological damage in New Zealand: possums (*Trichosurus vulpecula*), ship rats (*Rattus rattus*), and stoats (*Mustela erminea*) (Brown, et al., 2015). From here on, the term ‘predators’ refers to these three species plus Norway rats (*Rattus norvegicus*). The house mouse (*Mus musculus*) is specifically excluded as a predator in the context of this paper and is not a target species for ZIP. Aside from the estimated 25 million native birds they kill each year (Russell, et al., 2015), predators cost New Zealand hundreds of millions of dollars annually, both in terms of revenue lost and in control costs (Clout, 2011), and they impact the country’s primary production base through the transmission of diseases such as bovine tuberculosis (Coleman & Caley, 2000).

New Zealand has an impressive track record in the eradication of invasive mammalian predators from offshore islands for the protection of native biodiversity. Since the first successful eradication in 1964 (Towns & Broome, 2003), 134 islands have been completely freed from invasive mammals (Parkes, et al., 2017a). Although costs vary widely from island to island, the initial eradication cost is in the order of NZ$300/ha (Parkes et al., 2017b); and the ongoing biosecurity surveillance costs of these islands typically ranges from NZ$17 to NZ$160/ha per annum (New Zealand Department of Conservation (DOC) unpublished data, 2017). These costs *exclude* incursion response. For example, the stoat incursion response on Kapiti Island in 2010–2011 cost approximately NZ$600,000 (NZ$305/ha) (King, et al., 2014). These predator-free islands are considered to be the ‘jewels’ of the conservation crown; however, they represent only 58,921 ha, or <0.01% of the land area of New Zealand (Parkes, et al., 2017a).

For most of the New Zealand mainland, where restricting the reinvasion of predators is currently not possible, the management model used is the ongoing suppression of predator populations. Currently the main tool used by the major predator management agencies (DOC, TB Free New Zealand, Regional Councils) for large scale (up to 100,000 ha) predator control is repeated pulsing of aerially applied sodium fluoroacetate (1080) toxin, typically every three to five years (Brown, et al., 2015; Elliott & Kemp, 2016). The current annualised cost of this is approximately NZ$10/ha (Brown, et al., 2015). The benefits of this technique are of limited duration without ongoing sustained control, because not all individuals are removed from the treatment area, and immigration is uncontrolled so predator populations are able to recover (Griffiths & Barron, 2016).

The alternative, ground-based predator control methods rely on either a knockdown of the resident predator population, followed by ongoing suppression to low levels, or seasonal control to realise biodiversity benefits (e.g. for the native bird breeding period). This work is relatively labour intensive (via trapping or toxins in bait stations) and is presently undertaken over areas of up to 50,000 ha (e.g. Murchison mountains stoat trapping; Hegg, et al., 2013). The current annualised cost of this work is in the order of NZ$25 to NZ$60/ha depending on the scale and intensity of the control efforts and target predator species (Brown, et al., 2015).

Predator exclusion fencing, a physical mesh fence with a solid steel capping, is also used to recreate eradication-like conditions on the mainland (colloquially, New Zealand’s North and South Islands) by providing a physical barrier to halt reinvasion (Burns, et al., 2012). Predator fencing is scale-limited by terrain and cost, with the cost of recently constructed fences ranging from NZ$253–NZ$461/linear metre (Curnow & Kerr, 2017), with ongoing maintenance costs estimated to be 4% of capital costs per annum for the life of the fence (Norbury, et al., 2014), and eradication costs additional. Debate continues on the ecological, social and financial return on investment for predator fencing (Scofield, et al., 2011; Scofield & Cullen, 2012; Innes, et al., 2012; Norbury, et al., 2014).

To dramatically improve the status of New Zealand’s biodiversity, a step change is required in the ability to manage predators, and the cost of doing so. The New Zealand Government has declared the goal of a predator-free New Zealand by 2050 (Cabinet, 2016). In order to

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achieve this ambitious goal, the country will need to heed the call of The Royal Society of New Zealand (2014), for urgent action to develop novel approaches and to improve existing tools to protect the country's environment and economy.

Remove and protect model

One novel approach being investigated is the 'remove and protect' model, entailing complete removal of predators from an area and then protection against reinvasion. In essence, this creates permanent 'island' eradications within large landscapes of the New Zealand mainland. A research and development entity, Zero Invasive Predators Ltd (ZIP; founded in 2015), has been established with the purpose of developing the 'toolbox' to enable this model.

The remove and protect model involves three streams of research and development:

Initial removal of target predators

The most common and most successful technique for island eradication has been the aerial application of the toxin brodifacoum (Howald, et al., 2007; Parkes, et al., 2011). However, the use of this technology in New Zealand is governed by a Code of Practice (Epro Ltd. 2006) that limits its current use to offshore islands and stock-free areas of the mainland behind predator fences – preventing its immediate application in the remove and protect model. As a result, eradicating predators on the New Zealand mainland will likely require new techniques to be developed or novel refinement of the application of existing tools – refer to Case Study 1 for one such example.

Defending a line to protect against reinvasion

Implementing a campaign of the scale of predator-free New Zealand by 2050 (Cabinet, 2016) will require the ability to divide the country up into manageable land parcels for progressive removal operations. Predator fencing has allowed small areas to be treated as 'islands' on the mainland but has limited application because of rugged terrain and/or social acceptance (Clapperton & Day, 2001; Burns, et al., 2012). Dividing up the country will require additional approaches; the creation of a virtual barrier is one such approach – refer to Case Study 2.

Detecting and removing invaders before they significantly impact on the predator-free area

Traditionally, in the island eradication context, biosecurity surveillance consists of intensive networks of passive devices to find individual invaders (Russell, et al., 2008). In order to ensure the remove and protect model is scalable, and to protect any significant predator-free investment, there is a need to develop a minimal infrastructure detection system that can facilitate timely incursion response before significant ecological damage is incurred – refer to Case Study 3 for detection concepts being explored.

Changing the cost model

Eradication is the most cost-effective methodology for predator management (Pascal, et al., 2008), so long as long-term biosecurity costs are manageable, as the upfront costs of removal only need to be found once. However, on the mainland, where reinvasion into management sites is typically not controllable, the most cost-efficient technique at present is to aim for predator suppression over as large a land area as affordable, in the knowledge that it will need to be repeated *ad infinitum* to maintain the gains achieved. In New Zealand, where a relatively modest budget for predator control (given the scale of the issue at hand) is largely static year-on-year, the cyclical pattern of suppression means that only a limited land area can be managed and that cannot expand without increased investment.

The remove and protect model seeks to change that cost structure. By treating blocks of land like island eradications, i.e. removing all predators and managing reinvasion to zero, those gains can be secured, and the predator management programme can be expanded to treat new land areas. Due to the greater expected biodiversity outcomes derived from complete predator absence in the long term (Ismar, et al., 2014; Towns, et al., 2016), i.e. a larger ecological return on investment, the initial management costs can be greater than those currently afforded for suppression, especially as they are a one off cost. However, for this cost structure to be feasible, the remove and protect model must achieve similar cost profiles to those of island or fenced sanctuary eradications in both the removal and maintenance phases. The initial targets ZIP is currently working to are: initial predator removal costs of NZ$100/ha (cf. NZ$300/ha for island eradications; Parkes, 2017b); NZ$200/m for installation of a virtual barrier (cf. NZ$253−NZ$461/m for predator fencing; Curnow & Kerr, 2017); and NZ$50/ha/annum for detection and response (cf., for example, NZ$160/ha per annum for biosecurity surveillance on Ulva Island; DOC unpublished data, 2017). All costs exclude Goods and Services Tax (GST).

A focussed approach: Zero Invasive Predators Ltd (ZIP)

The opportunity to establish a public-philanthropic partnership presented itself when the NEXT Foundation approached DOC to invest in 'transformative change' for conservation. In what is a first for DOC, the decision was made to 'spin out' of Government and establish ZIP as a limited liability company (with NEXT Foundation as the sole shareholder). Founded in 2015, the intention was that ZIP would be tightly focussed on the core challenge of developing a new model for predator management; the equivalent of taking a specialist research and development unit and sheltering it from the rest of a business until the problem is 'solved'. It was further considered that freedom from Government would provide the best environment in which to remain agile and innovative.

While ZIP has a business structure, it does not have commercial motives. Any self-generated Intellectual Property is held for New Zealand, effectively making it openly available to those in New Zealand who want to use or build upon it. The founding constitution confirms this 'not for profit' stance, with any products to be sold at the most accessible price point in New Zealand (while reserving the right to profit from international sales), with any profit to be reinvested in conservation, rather than returned as a dividend to shareholders. ZIP is also recognised as a Registered Charity by the Charities Commission (the governing body in NZ). This charitable status has aided in securing further philanthropic investment (beyond NEXT Foundation) as donations, which are tax deductible in New Zealand.

Some of the high-level goals of ZIP, such as removal of possums and a reduced reliance on cyclic toxin applications, have also attracted support from New Zealand dairy companies, who share those intentions (F. Eggleton, Fonterra Co-operative Group, pers. comm). This support includes non-shareholding investment in the research and development programme, thereby further enhancing the unique public-philanthropic-private investment positioning of ZIP.

Operating culture – try, sense, respond

Ecological systems are usually complex and therefore the development approach of ZIP is to 'try, sense, and respond'. Potential solutions are suggested, techniques and tools are rapid-prototyped and placed in the field as soon as possible, impacts are measured, and prototypes are refined as soon as required. The 'try, sense, respond' approach allows rapid learning about real world constraints, which in turn informs the next iteration of development and testing.

This operating style aims to recognise failure quickly, to expose what we don't know, and to maximise the return on effort and resources. Supporting this 'fast fail' approach, field trials of prototypes typically begin at small scale, i.e. less than five units, in the expectation that limitations will be exposed and the prototype redesigned. Once the prototype shows sufficient promise, the trial is scaled-up in stages, going from, for example, 50 to 100 units, then many hundreds of units, etc. to test if the statistical performance holds as the scale increases. Alternatively, if the prototype fails catastrophically at the small scale, and no practicable alternatives are found, the trial is shut down to minimise loss of investment.

This operating culture is strengthened by a diverse, highly-skilled team, purpose-built for research and development. Scientists and engineers co-design field trials and technologies, field rangers actively test prototypes, with timely data analysis by a specialist modeller. Input from all aspects of the team feeds into each step of the development process, enabling rapid evolution of the project. All team members spend time at the field site(s) to remain grounded in the challenge.

Development in the field

ZIP, under permission from DOC (the land manager), has established a 391 ha forested site at Bottle Rock Peninsula, Queen Charlotte Sound, Marlborough (41°06'30" S, 174°14'06" E) dedicated to field trialling the remove and protect system, and its component prototype parts. Remove and protect is well suited to peninsulas as they are easier to defend, with only one major exposed front (with the sea 'protecting' the remainder). Interception efforts can then be concentrated within a relatively small zone to protect a much larger area.

Bottle Rock Peninsula was selected as it offered the ideal initial size for rats and possums, and was a favourable shape (2 km narrow neck with a bulbous peninsula). Importantly, this peninsula is not a site of high biodiversity priority for DOC (unpublished data, 2015), therefore it is able to be manipulated without risk to vulnerable native species. However, it does enable a 'real world' assessment of new or modified technologies. [NB: the majority of the field trials carried out at Bottle Rock to date have excluded stoats on account of their home range size, mobility, and our current lack of sensitive detection devices rendering robust stoat research impracticable.]

Evaluation of the performance of the remove and defend model at Bottle Rock Peninsula uses a 'systems design' approach (Cabrera, et al., 2008), assessing the whole, as opposed to a reductionist approach which seeks to understand the role of the individual elements to explain the utility of the system. The goal is to prove the system works, not just some parts of it, hence multiple tools need to be tested simultaneously in the defence system. Individual considerations are secondary and are investigated by 'switching off' components to specifically test their relative impact on the system's performance.

REMOVE AND PROTECT CASE STUDIES

Case study 1: Removal – '1080 to Zero'

It is expected that an aerially applied tool will be required for the initial removal of predators at large-scale implementation sites. Some of the early work developing techniques for island eradications investigated sodium fluoroacetate (1080) as an option (McFadden & Towns, 1991; Moors, 1985). However, it was subsequently discounted because of its acute toxicity and the perception that some individuals of the target populations could detect it in the bait and avoid it (McFadden & Towns, 1991). There has been significant improvement since that work, namely prefeeding to increase toxicant uptake (Nugent, et al., 2011) and manufacturing quality control (Nugent, et al., 2010; Nugent, et al., 2012). Extensive use in suppression operations has refined aerial 1080 use, but those operations still do not remove all target individuals (Elliott & Kemp, 2016).

ZIP sought to test whether dual aerial 1080 operations, each using different bait (to overcome learnt aversion; Ross, et al., 2000) and coupled with multiple prefeed applications, could completely remove rats and possums. Success was deemed to be functional extinction. The thresholds for achieving functional extinction were set at ≤1 possum per 400 ha (OSPRI, 2014); and ≤1 rat per 100 ha (Innes, et al., 2011).

The trial was carried out on a 1,600 ha area (39°15'30" S, 174°07'45" E) on the north-eastern slope of Mt Taranaki. A 400 ha core, set back with a 1 km buffer to minimise reinvasion compromising the results (Griffiths & Barron, 2016), was intensively monitored for surviving rats and possums after treatment with toxin. The trial excluded stoats due to the scale being insufficient to account for stoat home range size and mobility (Murphy & Dowding, 1994; Murphy & Dowding, 1995).

Prior to commencing the trial, monitoring (using peanut-butter filled chew cards, self-manufactured using corflute supplied by Pest Control Research and Pic's peanut butter – Picot Productions Ltd) was deployed three times for between two and 10 nights using between 36 and 55 cards each time. The cards were placed every 50 metres on 2–3 randomly selected lines (of between 1.6 and 2 km in length) within the 400 ha core. The purpose of this monitoring was not to measure a relative abundance, but merely to confirm presence of target animals. 98% of total cards deployed were chewed by rats, 6% of total cards deployed were chewed by possums.

The first phase of baiting consisted of multiple prefeed baiting of non-toxic RS5, 6 g, cinnamon-masked cereal pellets (manufactured by Orillion, formerly Animal Control Products) applied by helicopter-slung bait-spreading bucket – at (on-ground application rates of) 4 kg/ha; 2 kg/ha (20 days later); 1 kg/ha (21 days later); 1 kg/ha (47 days later). Application of (on-ground rate) 4 kg/ha of RS5, 6 g, 0.15% 1080, cinnamon-masked cereal pellets (Orillion) followed 21 days later. Bait was flown with a 50% swath overlap, as per island eradication best practice (Broome, et al., 2014), to ensure no gaps in bait coverage. Baiting was intended to be completed in winter, when 1080 has been shown to be most effective (Veltman & Pinder, 2001; Gillies, et al., 2003); but adverse weather resulted in the toxin being applied on 1 December 2016.

In an effort to detect survivors, 835 chew cards were deployed on a 50 m × 100 m grid throughout the 400 ha core four nights after the toxin application, and checked every eight days, for a total of 42 days. In addition, 421 pre-weathered tracking tunnels installed on a 100 m × 100 m grid were baited 17 days into the detection period and maintained live until the same 42-day period post-toxin application had passed. Furthermore, 80 motion-activated cameras (Little Acorn, LTL5200 and LTL5300) were deployed in a 100 m × 100 m grid in the north-eastern corner of the ZIP block for the final 17 nights of the detection period to validate the performance of the other detection devices.

Functional extinction of possums was considered to be achieved, with only one possum detection (chew card) recorded across 36,430 detection nights across all applicable detection devices (chew cards and cameras). The same was not achieved for rats, with 42 detections (two chew cards; 25 tracking tunnels; 15 camera detections) recorded over 46,755 detection nights.

In light of the numbers of surviving rats, we attempted to individually test them for any learnt bait aversion (rather than undertake the second phase of toxic aerial baiting). Research by Morgan (2004) suggested that cereal pellets cannot overcome aversion if created by cereal pellets in the first place; however, that study did not include prefeeding. Morgan, in the same work, states that 'learnt food safety' (i.e. learnt through prefeeding) is a very strong behaviour once established. Ross et al. (2000) achieved 30% mortality in captive 1080 bait-shy possums when 'postfed' with cereal (compared with 0% of non-postfed possums). We sought to determine whether it is possible, in the wild, to overcome any bait aversion in the surviving rats through prefeeding with the different bait, even if it is cereal.

The 1,600 ha trial area was prefeed-baited twice, using non-toxic Wanganui #7, 6g, double orange-masked cereal pellets (Orillion) from a helicopter-slung bait-spreading bucket, seven days apart (58 and 65 days after the first toxin application). McGregor live-capture traps were set in areas of known detections and baited with a single Wanganui #7 0.15% 1080 6g double orange-masked cereal pellet (Orillion). Traps were baited in such a way that the rat had to interfere with the pellet to trigger the trap. Traps were in place for 270 trap nights across various detection sites.

Thirteen rats were caught that were deemed to be survivors based on the weight:age profile (Bentley & Taylor, 1965); animals that were very likely to have been present when the initial toxin application was carried out. Of those, six were found dead in the trap (following consumption of a lethal dose of the bait), while an additional two were alive but showed clear signs of toxicosis with bait consumed (with death expected). The remaining five animals were all alive and were subsequently euthanised. While those rats found alive suggest some level of aversion, the trap itself may have contributed to the aversion once triggered, or alternatively they may have received a sub-lethal dose and did not return to the bait. It is expected that some rats did not encounter the live capture traps or chose to avoid them (and the bait within).

If the second aerial toxic baiting had been carried out, the total cost of the novel prescription (including all prefeed and toxic baiting applications) is estimated at approximately NZ$90/ha, excluding costs associated with gaining regulatory approvals. There is potential for this cost to reduce further with economies of scale and reduced prefeed applications.

ZIP retested the hypothesis in a trial on the West Coast of the South Island during the second half of 2017. After the first phase of baiting (two prefeed applications, and one toxin application using Wanganui #7 0.15% 1080 6g double orange-masked cereal pellet (Orillion)), zero rats and possums were detected over 83,410 detection nights across 55 days post-toxin application (unpublished data). The trial was deemed a success, and ended here.

Case study 2: Protect – the 'virtual barrier'

The virtual barrier is a system that aims to exclude 99% of rats, and 95% of possums that attempt to enter a protected area. The virtual barrier being tested across the 2 km neck at Bottle Rock Peninsula consists of multiple defence lines, 100 m apart, comprising kill (for rats) and live capture (for possums) traps only, with no toxins currently deployed in the system. Devices are placed at high intensity along each defence line, one every 10 m, based on the assumption that this spacing would 'guarantee' no animals could breach the barrier without encountering a device, i.e. if the target animal is on the ground it is never more than five metres from a device as it passes through a line. Whether they choose to interact with that device is another matter entirely!

Possums

The most effective virtual barrier for possums tested to date consisted of four lines of leg hold traps (PCR #1, Pest Control Research) running across the peninsula and a 400 m long line of leg hold traps running along the central, prominent ridge through the barrier. The leg hold traps are set in a custom-made platform raised 1.2 metres above the ground (to avoid non-target captures of weka, *Gallirallus australis*, a ground dwelling endemic rail). The traps are visually lured with a plain white corflute card (Connovation Ltd) nailed to the tree approximately 30 cm above the platform. Each platform has a wooden ramp attached, at 60° to the horizontal. In addition to preventing weka access, alternating trials by ZIP have shown that ramps improve trap effectiveness by 18% (95% C.I. [2.5%, 29%]) compared with non-ramped traps.

Traditionally, live-capture leg hold traps must be physically inspected by the trapper every day in order to comply with New Zealand animal welfare legislation. ZIP has developed an automated, remote reporting system that uses a magnetically switched trap transmitter to advise that a trap has been sprung, via a 433 MHz 'daisy chain' and the Iridium satellite network. To date (May 2017), the remote reporting system has been in service for more than 580,000 trap nights and has remotely reported over 500 possum captures – there has not been a single false negative in this time. In conjunction, the NZ Ministry for Primary Industries has developed industry guidelines to allow the automated reporting of live-capture traps, while conforming to animal welfare standards as required by law (MPI, 2016). This innovation has reduced the labour cost of servicing the traps by 95%, with only sprung traps needing to be checked by the trapper.

During the period from 26 November 2016 to 17 May 2017, the virtual barrier caught 127 possums, with at least 11 possums breaching the barrier; i.e. 8% 'leakage' (95% confidence interval, [4%, 14%]). Leakage was determined from the number of possums killed in the protected area (beyond the barrier), using leg hold traps, set up as per the barrier, but placed on a one per 50 ha density, divided by the total number that attempted to breach the barrier (number killed in the barrier plus number killed beyond it). In addition, a detection network of 554 chew cards (self-filled as described in the removal case study), serviced every three weeks, confirms the ongoing absence or presence of possums in the protected area. On average, approximately 18 possums/month attempted to cross the 2 km wide barrier, with 1.5 possums/month succeeding. Improvements to the system have been identified, and therefore future versions of the barrier are expected to approach the target of ≤ 5% leakage.

Ship rats

The current virtual rat barrier at Bottle Rock consists of six lines of 'Tun200s' (two DOC200 single action stainless steel kill traps (CMI Springs), in custom built 'run-through tunnel' wooden trap box). The wooden tunnels have a 72 mm diameter entrance hole and 265 mm long tunnel leading to the kill plates from both ends, to avoid non-target captures of weka which cannot fit inside the entrance hole nor stretch out to reach the traps themselves (currently <1 kill every 35,000 trap nights).

From 26 June to 26 October 2015, the virtual barrier caught 160 ship rats, with at least nine rats breaching the barrier; i.e. 5% leakage (95% confidence interval, [2.5%, 10%]). Leakage was estimated as described for possums in the previous section (e.g. number of rats killed on 100 m x 60 m grid of single-set DOC150 kill traps (CMI Springs) in 'standard' wooden boxes, placed throughout the peninsula beyond the barrier), in conjunction with the detection network of chew cards (as described above for possums) confirming the absence or presence of rats in the protected area. On average, approximately 40 ship rats/month attempted to cross the 2 km wide barrier, with two rats per month succeeding. All Tun200 traps were lured with peanut butter (Goodnature Ltd) during this period. We found no evidence to suggest that the effectiveness of identically lured, multiple lines of Tun200 traps declined with repeated presentation (effectiveness 40%, 95% C.I [33%, 46%], for all Tun200 lines treated as samples from the same population, that is irrespective of the line placement).

A variety of alternative food lures have subsequently been trialled including Nutella (Ferrero Australia Pty Ltd), Colby cheese (Mainland Ltd), milk chocolate (J.H. Whittaker and Sons Ltd), and peanut butter (Goodnature Ltd, and Pic's - Picot Productions Ltd). These lures performed similarly and intercepted on average 36% (95% C.I. [33%, 39%]) of rats, as measured by the percentage of rats that breached each line.

Costs of the barrier

Including the cost of track cutting and installation, the current capital cost of a multiple line, ship rat and possum virtual barrier at Bottle Rock Peninsula is approximately NZ$250/m (excl. GST). This cost is for a 20-year life, and includes device replacement, remote reporting system, and an automated lure dispenser (in development to further reduce labour costs).

The annual operating cost is approximately NZ$20/m (8% of capital cost).

Case study 3: Detection – a 'minimal infrastructure' system

Ship rats

Considerable effort has gone into understanding the exploratory behaviour of invading rats in predator-free spaces, with substantial individual variation identified in the roaming behaviour (Russell, et al., 2005; Russell, et al., 2008; Russell, et al., 2010; Innes, et al., 2011). Not unexpectedly, the majority of this work has been focussed on the individual, as current biosecurity detection systems are tailored towards intensively targeting the individual invader.

ZIP is conceptualising an alternative approach that looks beyond the individual, and rather focusses on the emergent population (if it happens). So long as the incursion events are infrequent, if the invading rat is alone and non-pregnant, then the scale of their individual impact is expected to be small and impacts only begin to have significance once a new population emerges (Norbury, et al., 2015; Elliott & Kemp, 2016). This is the point of intervention ZIP proposes to target.

Targeting the first generation (Generation One) of a pregnant female provides up to 11 individuals, 10 juveniles plus mother (Innes, 2005) to trigger detection devices, rather than the sole invader, greatly increasing the chances of interaction. Furthermore, the anticipated dispersal footprint of Generation One is likely to lend itself to a minimal infrastructure network spacing (perhaps one detection device every 20 ha, based on emerging data from ZIP trials such as that below). This network could be further tailored to be predominantly coastal and waterway biased, to maximise the probability of encounter. In addition, we estimate that we could have up to 100 days to detect and remove the first generation of invaders, before those juveniles reach sexual maturity and begin breeding themselves (based on reproductive biology; Innes, 2005). Conversely, this approach will require bigger treatment areas to remove the entire emerging population. The response could well be aerially based, rather than the ground-based responses traditionally deployed for island incursions.

A ZIP field trial is currently underway (during the drafting of this paper) at the confluence of the Jackson and Arawhata Rivers, South Westland (44°03'00" S, 168°43'32" E) whereby a mother ship rat and her offspring have been released into an area of very low rat abundance to observe their dispersal footprint. Early indications, based on the distance between release point and subsequent trap capture points, are that some individual offspring dispersed at least 650 m from the natal den location by the time they were 86 days old.

If the concept works, the capital cost of installing this system today would be NZ$20/ha. The annual surveillance cost would be NZ$4/ha (using an automated reporting kill trap as the 'sentinel' detection device), with an annual response cost of NZ$5/ha (assuming a leakage rate of 0.5%).

Possums

Possums, once isolated, roam over considerable ranges, in the order of 50–100 ha (Sweetapple & Nugent, 2009; OSPRI, 2014), presumably looking for other possums. If possum incursions are infrequent, their slow breeding rates (Cowan, 2005) and curiosity (Carey et al., 1997) suggest that delayed detection and response may be all that is necessary to prevent possum re-establishment.

ZIP is currently trialling a minimal 'lethal detection' network for possums at Bottle Rock Peninsula. Six leg-hold traps, deployed as in the virtual barrier (excluding ramp) but spaced at approximately one per 50 ha, have been established beyond the virtual barrier. In the 12 months since its deployment, this network has prevented possum reestablishment; with 17 possums caught to June 2017 (and no sustained detections on the 'background' chew card network, as described in case study 2). The capital cost of installing this system today would be NZ$10/ha, with a current operating cost of detection and response of approximately NZ$5/ha/annum.

Automated reporting system

To support these minimal infrastructure detection networks, development of an automated system for near real-time updates on the status of remove and protect sites is continuing. ZIP has already developed the ability to use daisy chain communication for short range data transmission, e.g. trap lines in a barrier setting. However, a landscape scale network will require a different transmission technology – one that can transmit reliably over large distances, in rugged or forested terrain (Jones, et al., 2015). Recent advances in the international telecommunications industry are seeing the emergence of low powered, long range radio technology (LoRa). A small number of sensitive receiving stations allows the use of many battery-powered transmitters across a landscape. LoRa, used in combination with satellite-based communications, is likely to be the platform technology on which to build an incursion notification system for these remote networks.

CONCLUSION

The New Zealand Government has announced the goal of being predator-free by 2050. Momentum is building on this goal, with the Predator Free 2050 Ltd company established with a board of directors to guide strategic investment into projects of significance (Anon., 2016). While New Zealand has an internationally enviable track record in island eradications and developed the predator fenced sanctuary approach, these methodologies cannot be scaled on the mainland.

It is widely acknowledged that new technologies, along with a shift in operating model and cost structure, will be required to completely eradicate predators from the mainland. Such a shift from the suppression paradigm could utilise the remove and protect model, where peninsulas are able to be converted into 'islands' for eradication operations. Zero Invasive Predators (ZIP), a not-for-profit research and development company founded in 2015, is helping to develop the techniques required to enable this model on the mainland.

Further trials are underway to use a novel prescription of dual aerial 1080 operations to drive initial removal at a cost of less than NZ$100/ha (with no more than two prefeed applications per toxin application). In-forest capability exists now to intercept over 95% of all rats and possums using a virtual barrier at a capital cost of approximately NZ$250/m and an annual operating cost of less than NZ$40/m. The initial testing of a minimal infrastructure detection system shows promising signs of success. Large social strides are still required to make predator-free New Zealand a reality, but the first tentative technical steps are being taken now.

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REFERENCES

Anon. (2016). *Predator Free 2050 Ltd. Board Appointed.* Press release 30 November 2016. Wellington: Office of the Minister of Conservation.

Bentley, E.W. and Taylor, E.J. (1965). 'Growth of laboratory-reared ship rats (*Rattus rattus* L.)'. *Annals of Applied Biology* 55: 193–205.

Broome, K., Cox, A., Golding, C., Cromarty, P., Bell, P. and McClelland, P. (2014). *Rat Eradication Using Aerial Baiting: Current Agreed Best Practice Used in New Zealand (Version 3.0)*. Wellington: Department of Conservation.

Brown, K., Elliott, G., Innes, J. and Kemp, J. (2015). *Ship Rat, Stoat and Possum Control on Mainland New Zealand: An Overview of Techniques, Successes and Challenges.* Wellington: Department of Conservation.

Burns, B., Innes, J. and Day, T. (2012). 'The Use and Potential of Pest-proof Fencing for Ecosystem Restoration and Fauna Conservation in New Zealand'. In: M. Somers and M. Hayward (eds.) *Fencing for Conservation: Restriction of Evolutionary Potential or a Riposte to Threatening Processes?* pp. 65–90. New York: Springer-Verlag.

Cabinet (2016). *Accelerating Predator Free New Zealand*. CAB-16-MIN-0335. Wellington: Cabinet Economic Growth and Infrastructure Committee.

Cabrera, D., Colosi, L. and Lobdell, C. (2008). 'Systems thinking'. *Evaluation and Program Planning* 31: 299–310.

Carey, P.W., O'Connor, C.E., McDonald, R.M. and Matthews, L.R. (1997). 'Comparison of the attractiveness of acoustic and visual stimuli for brushtail possums'. *New Zealand Journal of Zoology* 24: 273–276.

Clapperton, B.K. and Day, T.D. (2001). 'Cost-effectiveness of exclusion fencing for stoat and other pest control compared with conventional control'. *DOC Science Internal Series* 14: 5–19.

Clout, M.N. (2011). 'Ecological and Economic Costs of Alien Vertebrates in New Zealand'. In: D. Pimentel (ed.) *Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species*, pp. 283–291. Boca Raton: CRC Press.

Coleman, J. and Caley, P. (2000). 'Possums as a Reservoir of Bovine TB'. In: T. L. Montague (ed.) *The Brushtail Possum. Biology, Impact and Management of an Introduced Marsupial*, pp. 92–104. Lincoln: Manaaki Whenua Press.

Cowan, P.E. (2005). 'Brushtail Possum'. In: C.M. King (ed.) *The Handbook of New Zealand Mammals*, pp. 56–80. Auckland: Oxford University Press.

Curnow, M. and Kerr, G.N. (2017). *Predator Free Banks Peninsula: Scoping Analysis*. LEaP Research Report No. 44. Lincoln: Lincoln University.

Elliott, G. and Kemp, J. (2016). 'Large-scale pest control in New Zealand beech forests'. *Ecological Management and Restoration* 17: 200–209.

Epro Ltd. (2006). *Code of Practice: Aerial and Hand Broadcast of Pestoff Rodent Bait 20R for the Intended Eradication of Rodents from Specified Areas of New Zealand*, Wellington: New Zealand Food Safety Authority.

Gillies, C., Campbell, J., Marsh, N. and Gembitsky, M. (2003). 'Seasonal Differences in Bait Acceptance by Forest-dwelling Rats Following Simulated Aerial 1080 Possum Control Operations in New Zealand: Interim Results'. In: G. Singleton, L. Hinds, C. Krebs and D. Spratt (eds.) *Rats, Mice and People: Rodent Biology and Management. ACIAR Monograph 96*, pp. 343–345. Canberra: Australian Centre for International Agricultural Research.

Griffiths, J.W. and Barron, M.C. (2016). 'Spatiotemporal changes in relative rat (*Rattus rattus*) abundance following large-scale pest control'. *New Zealand Journal of Ecology* 40: 371–380.

Hegg, D., MacKenzie, D.I. and Jamieson, I.G. (2013). 'Use of Bayesian population viability analysis to assess multiple management decisions in the recovery programme for the endangered takahe *Porphyrio hochstetteri*'. *Oryx* 47: 144–152.

Hitchmough, R. (2013). 'Summary of Changes to the Conservation Status of Taxa in the 2008–11 New Zealand Threat Classification System Listing Cycle'. *New Zealand Threat Classification Series 1*. Wellington: Department of Conservation.

Howald, G., Donlan, C.J., Galvan, J.P., Russell, J.C., Parkes, J., Samaniego, A., Wang, Y., Veitch, D., Genovesi, P., Pascal, M., Saunders, A. and Tershy, B. (2007). 'Invasive rodent eradication on islands'. *Conservation Biology* 21: 1258–1268.

Innes, J. (2005). 'Ship Rat'. In: C. M. King (ed.) *Handbook of New Zealand Mammals*, pp. 187–203. Auckland: Oxford University Press.

Innes, J., Watts, C., Fitzgerald, N.L., Thornburrow, D., Burns, B., MacKay, J. and Speedy, C. (2011). 'Behaviour of invader ship rats experimentally released behind a pest-proof fence, Maungatautari, New Zealand'. In: C.R. Veitch, M.N. Clout, and D.R. Towns (eds.) *Island invasives: eradication and* management, pp. 437–440. Occassional Paper SSC no. 42. Gland, Switzerland: IUCN and Auckland, New Zealand: CBB.

Innes, J., Lee, W.G., Burns, B., Campbell-Hunt, C. and Watts, C. (2012). 'Role of predator-proof fences in restoring New Zealand's biodiversity: a response to Scofield, et al. (2011)'. *New Zealand Journal of Ecology* 36: 232–238.

Ismar, S.M.H., Baird, K.A., Gaskin, C.P., Taylor, G.A., Tennyson, A.J.D., Rayner, M.J., Bettesworth, D., Fitzgerald, N., Landers, T.J. and Imber, M.J. (2014). 'A case of natural recovery after the removal of invasive predators – community assemblage changes in the avifauna of Burgess Island'. *Notornis* 61: 188–195.

Jones, C., Warburton, B., Carver, J. and Carver, D. (2015). 'Potential applications of wireless sensor networks for wildlife trapping and monitoring programs'. *Wildlife Society Bulletin* 39: 341–348.

King, C.M., Veale, A., Patty, B. and Hayward, L. (2014). 'Swimming capabilities of stoats and the threat to inshore sanctuaries'. *Biological Invasions* 16: 987–995.

McFadden, I. and Towns, D. (1991). *Eradication Campaigns Against Kiore (*Rattus exulans*) on Rurima Rocks and Korapuki, Northern New Zealand. Science and Research Internal Report No 97.* Wellington: Department of Conservation.

Moors, P.J. (1985). 'Eradication campaigns against *Rattus norvegicus* on the Noises Islands, New Zealand, using brodifacoum and 1080'. *ICBP Technical Publication* 3: 143–155.

Morgan, D.R. (2004). 'Maximising the Effectiveness of Aerial 1080 Control of Possums (*Trichosurus vulpecula*)'. PhD thesis. Lincoln: Lincoln University.

MPI (2016). *Remote Monitoring of Live Capture Traps for Vertebrates: Guidelines for Good Practice*. Wellington: Ministry for Primary Industries.

Murphy, E.C. and Dowding, J.E. (1994). 'Range and diet of stoats (*Mustela erminea*) in a New Zealand beech forest'. *New Zealand Journal of Ecology* 18: 11–18.

Murphy, E.C. and Dowding, J.E. (1995). 'Ecology of the stoat in *Nothofagus* forest: home range, habitat use and diet at different stages of the beech mast cycle'. *New Zealand Journal of Ecology* 19: 97–109.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. and Kent, J. (2000). 'Biodiversity hotspots for conservation priorities'. *Nature* 403: 853–858.

Norbury, G., Hutcheson, A., Reardon, J. and Daigneault, A. (2014). 'Pest fencing or pest trapping: a bio-economic analysis of cost-effectiveness'. *Austral Ecology* 39: 795–807.

Norbury, G.L., Pech, R.P., Byrom, A.E. and Innes, J. (2015). 'Density-impact functions for terrestrial vertebrate pests and indigenous biota: guidelines for conservation managers'. *Biological Conservation* 191: 409–420.

Nugent, G., Morgan, D., Clayton, R. and Warburton, B. (2010). 'Improving the efficacy of aerial poisoning of brushtail possums (*Trichosurus vulpecula*) through reduced fragmentation of bait'. *International Journal of Pest Management* 57: 51–59.

Nugent, G., Warburton, B., Thomson, C., Sweetapple, P. and Ruscoe, W.C. (2011). 'Effect of prefeeding, sowing rate and sowing pattern on efficacy of aerial 1080 poisoning of small-mammal pests in New Zealand'. *Wildlife Research* 38: 249–259.

Nugent, G., Twigg, L.E., Warburton, B., McGlinchy, A., Fisher, P., Gormley, A.M. and Parkes, J.P. (2012). 'Why 0.02 %? A review of the basis for current practice in aerial 1080 baiting of rabbits in New Zealand'. *Wildlife Research* 39: 89–103.

OSPRI (2014). *Our First Year|2013/2014 OSPRI Annual Report and TBfree Research and Disease Control Report*. Wellington: OSPRI.

Parkes, J., Fisher, P. and Forrester, G. (2011). 'Diagnosing the cause of failure to eradicate introduced rodents on islands: brodifacoum versus diphacinone and method of bait delivery'. *Conservation Evidence* 8: 100–106.

Parkes, J.P., Nugent, G., Forsyth, D.M., Byrom, A.E., Pech, R.P., Warburton, B. and Choquenot, D. (2017a). 'Past, present and two potential futures for managing New Zealand's mammalian pests'. *New Zealand Journal of Ecology* 41: 151–161.

Parkes, J.P., Byrom, A. and Edge, K.-A. (2017b). 'Eradicating mammals on New Zealand island reserves: what is left to do?' *New Zealand Journal of Ecology* 41: 1–8.

Pascal, M., Lorvelec, O., Bretagnolle, V. and Culioli, J-M. (2008). 'Improving the breeding success of a colonial seabird: a cost-benefit comparison of the eradication and control of its rat predator'. *Endangered Species Research* 4: 267–276.

Ross, J.G., Hickling, G.J., Morgan, D.R. and Eason, C.T. (2000). 'The role of non-toxic prefeed and postfeed in the development and maintenance of 1080 bait shyness in captive brushtail possums'. *Wildlife Research* 27(1): 69–74.

Royal Society of New Zealand (2014). 'Challenges for Pest Management in New Zealand'. *Emerging Issues March 2014.*

Russell, J.C., Towns, D.R., Anderson, S.H. and Clout, M.N. (2005). 'Intercepting the first rat ashore'. *Nature* 437: 1107.

Russell, J.C., Beaven, B.M., MacKay, J.W.B., Towns, D.R. and Clout, M.N. (2008). 'Testing island biosecurity systems for invasive rats'. *Wildlife Research* 35: 215–221.

Russell, J.C., McMorland, A.J.C. and MacKay, J.W.B. (2010). 'Exploratory behaviour of colonizing rats in novel environments'. *Animal Behaviour* 79: 159–164.

Russell, J.C., Innes, J.G., Brown, P.H. and Byrom, A.E. (2015). 'Predator-free New Zealand: Conservation country'. *BioScience* 65: 520–525.

Scofield, R.P., Cullen, R. and Wang, M. (2011). 'Are predator-proof fences the answer to New Zealand's terrestrial faunal biodiversity crisis?' *New Zealand Journal of Ecology* 35: 312–317.

Scofield, R.P. and Cullen, R. (2012). 'Fenced sanctuaries need critical evaluation: a reply to Innes, et al. (2012)'. *New Zealand Journal of Ecology* 36: 239–242.

Sweetapple, P. and Nugent, G. (2009). 'Possum demographics and distribution after reduction to near-zero density'. *New Zealand Journal of Zoology* 36: 461–471.

Towns, D.R. and Broome, K.G. (2003). 'From small Maria to massive Campbell: forty years of rat eradications from New Zealand islands'. *New Zealand Journal of Zoology* 30: 377–398.

Towns, D.R., Borrelle, S.B., Thoreson, J., Buxton, R.T. and Evans, A. (2016). 'Mercury Islands and their role in understanding seabird island restoration'. *New Zealand Journal of Ecology* 40: 235–249.

Veltman, C.J. and Pinder, D.N. (2001). 'Brushtail possum mortality and ambient temperatures following aerial poisoning using 1080'. *Journal of Wildlife Management* 65: 476–481.