Predator-Free New Zealand: Conservation Country

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Eradications of invasive species from over 1000 small islands around the world have created conservation arks, but to truly address the threat of invasive species to islands, eradications must be scaled by orders of magnitude. New Zealand has eradicated invasive predators from 10% of its offshore island area and now proposes a vision to eliminate them from the entire country. We review current knowledge of invasive predator ecology and control technologies in New Zealand and the biological research, technological advances, social capacity and enabling policy required. We discuss the economic costs and benefits and conclude with a 50-year strategy for a predator-free New Zealand that is shown to be ecologically obtainable, socially desirable, and economically viable. The proposal includes invasive predator eradication from the two largest offshore islands, mammal-free mainland peninsulas, very large ecosanctuaries, plus thousands of small projects that will together merge eradication and control concepts on landscape scales.

Keywords: control, eradication, invasive species, islands, policy/ethics

Worldwide, introduced mammalian predators are eating island endemics to extinction (Blackburn et al. 2004). Since 1500 CE, over 60% of vertebrate extinctions have been on islands, with invasive species implicated in half of these (Tershy et al. 2015). In response, over 1000 eradications of introduced predators from islands around the world (Keitt et al. 2011) have created arks for threatened species, but such efforts are literally a drop in the ocean. Initiatives to remove invasive predators on a hitherto unimagined landscape scale are required for island conservation in the future (Nicholls 2013). In New Zealand, this is precisely what is being proposed by the Predator-Free New Zealand campaign: island sanctuaries at a national scale.

In 2012, the late physicist Sir Paul Callaghan proposed an “Apollo program” for New Zealand. His vision was not a space program but, rather, a mammalian-predator-free New Zealand (PFNZ). Audacious in scale, the plan is focused on the elimination of eight introduced mammalian predators (rodents: *Rattus rattus*, *Rattus norvegicus*, *Rattus exulans*, *Mus musculus*; mustelids: *Mustela furo*, *Mustela erminea*, *Mustela nivalis*; and the common brushtail possum: *Trichosurus vulpecula*) responsible for most of the estimated 26.6 million chick and egg losses for native bird species each year in New Zealand native forests and considerable losses to both primary production and tourism (calculations based on Innes et al. 2010; Hill 2012). The severe impact of invasive mammalian predators is linked to the absence of this guild before the arrival of humans approximately 700 years ago, since when one quarter of native bird species have gone extinct. New Zealand has eradicated all introduced mammals (predators and herbivores) from over 100 of its offshore islands (Towns et al. 2013), but in 50 years of pioneering and persistent effort, this has only increased the pest-free island area from 0.5% to just 10% (figure 1). Elsewhere on the main North and South Islands, there are now hundreds of regional control programs for invasive mammals that operate on a volunteer basis as well as predator control efforts by national and regional government agencies, but these programs are haphazardly located and can have little coordination across landscapes and jurisdictions (Glen et al. 2013a).

Under predicted climate change scenarios, small islands can no longer be considered a mainstay of biodiversity conservation (Courchamp et al. 2014). Callaghan’s ambitious proposal for PFNZ was to start by eradicating invasive mammalian predators from New Zealand’s largest offshore islands and from extremely large (more than 100,000 ha) mainland reserves on the main islands (the North and South Islands are colloquially referred to by New Zealanders as the *mainland*, and all other islands are referred to as *offshore*). This vision for a PFNZ has received public support and been championed by economist and philanthropist Gareth Morgan, fostering a new social movement that coincided in 2014 with the 50th anniversary of the first rodent eradication on a New Zealand offshore island. If it is successful, the eradication of these invasive predators would be an outstanding scientific and socioecological achievement and

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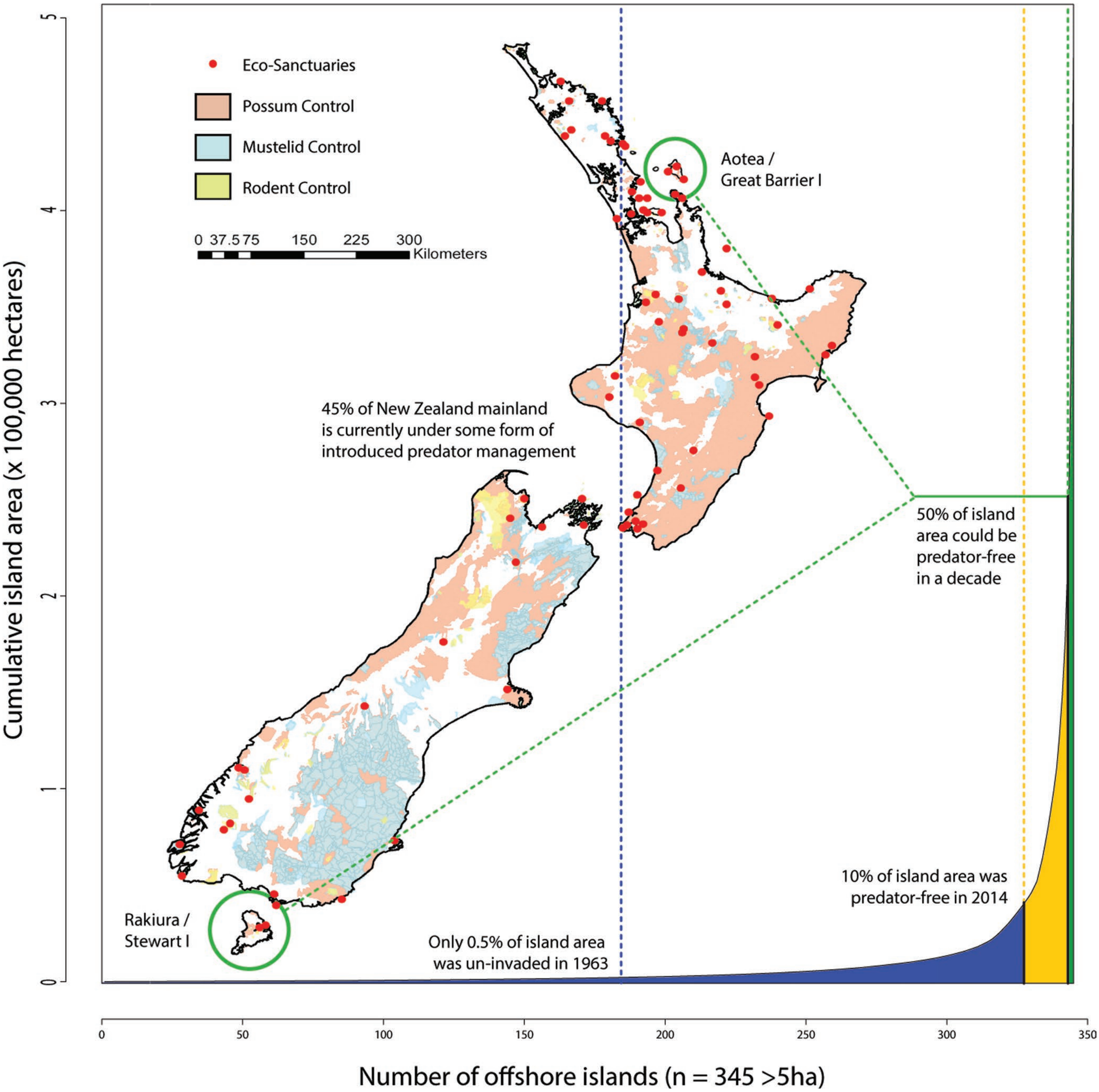

Figure 1. Cumulative introduced-predator-free offshore island area in New Zealand 1963–2014 (n = 105 mammal-free islands) and government mainland surveillance and control 2007–2014. Community-led intensively pest managed ecosanctuaries on the mainland (n = 60) and islands (n = 16) are indicated.

a beacon for invasive species control in other island nations. However, this ambitious project faces tremendous cross-disciplinary challenges (Goldson et al. 2015) that will require a sequence of enabling policies and actions.

Biological and technical challenges

New Zealand currently undertakes control or surveillance of invasive mammals across 45% of the country (figure 1), 11.8 million ha (EPA 2012), although only about half this area receives control in any given year. At intensively managed small sites (termed *ecosanctuaries*), eradication of invasive mammals is achieved using predator-proof fences. At other sites, suppression of invasive mammals to near zero is achieved using grids of bait stations and traps. These projects create the core to Callaghan's vision, and generate a halo around them of spillover benefits for native biodiversity in neighboring habitats (Glen et al. 2013a). However, ecosanctuaries represent less than 0.2% of New

Zealand's 26.4-million-hectare (ha) mainland, and this level of sustained management—the lynchpin of PFNZ—is only scalable to a few thousand ha. Beyond this, landscape-scale control of invasive mammals can only be achieved at present with aerial delivery of poison baits; the same technology that eradicates pests completely from smaller islands. So far, such operations—to 270,000 ha—have been undertaken only in unoccupied national parks and forest parks, but ground-based options for smaller (to 40,000 ha) rural areas with many cooperating landowners are also being trialed.

Invasive species control requires a long-term commitment and focus on enabling conditions (Norton 2009). Currently, critical biological barriers include understanding dispersal and reinvasion by target species and their behavior at low densities and integrating this understanding with advances in detecting and removing invaders across large spatial scales. Clearance of invasive mammals from areas greater than 100,000 ha cannot currently be achieved within a single operation, but instead requires a "rolling front" such as that currently being implemented on 3903 square kilometer (km^2) South Georgia Island for Norway rats and that proposed for North American beavers over 70,000 km^2 of Tierra del Fuego. However, the spatial scale of rodent eradications in New Zealand increased by an order of magnitude a decade from 1964 to 2004 (Clout and Russell 2006).

Techniques developed to minimize adverse side effects of island eradications such as managing the collateral impacts of undertaking invasive species control must be scaled and applied to the mainland (Towns et al. 2013). Control technologies can themselves impact nontarget species via unintentional trapping or consumption of poison or poisoned carcasses. Although there is demonstrable population-level recovery of native biota when invasive species are controlled, the accidental death of nontarget species is a longstanding concern that requires addressing in novel ways (Eason et al. 2002). Removing keystone invasive predators from ecosystems can also generate unexpected indirect effects such as mesopredator and competitor release (Ruscoe et al. 2011) that must be predicted and carefully managed. The optimal approach is to remove all species simultaneously (Dowding et al. 2009). The development of predator-proof exclusion fencing was motivated partly by this concern, although mice have survived this strategy in several established ecosanctuaries (Innes et al. 2012).

Key to achieving PFNZ will be the development of new technologies for effective and humane control of invasive predators. Currently, control of mammalian predators worldwide relies on technologies developed over 50 years ago—that is, mechanical single-capture traps and broad-spectrum anticoagulant poisons. These tools should be phased out and replaced with new technologies that achieve greater efficacy and public acceptance while simultaneously reducing costs (Campbell et al. 2015), such as automated self-resetting traps with remote monitoring (Blackie et al. 2014), engineered species-specific toxins (Rennison et al. 2013), highly attractive lures (Linklater et al. 2013), viruses as a delivery mechanism for fertility control agents (Cross et al. 2011) and the Trojan Female Technique to produce infertile males through the female mitochondrial line (Gemmell et al. 2013). These technologies have passed the proof-of-concept stage (Eason et al. 2010) but have been stalled by regulatory processes. Policy enabling the commercialization of these tools would open up the required scales of pest control, but is currently hampered by bureaucracy in registration procedures and a lack of investment funding to develop tools from conception to commercial viability (Eason et al. 2010).

Improvements are needed for all key target pest groups (e.g., Campbell et al. 2015). Currently, mustelids (especially stoats) are targeted by both ground trapping and by secondary poisoning after aerial sodium monofluoroacetate (1080) distributions. Aerial delivery of carnivore-specific toxins such as paraaminopropiophenone (PAPP; Eason et al. 2014) would allow more targeted or even larger scale control, although citizen application of PAPP in ground stations could also be undertaken on very large scales.

Social and political perspectives

Removing multiple introduced species from a large inhabited archipelago is at least as much an economic and social challenge as a biological one (Glen et al. 2013b). The New Zealand public associates its national identity strongly with a "100% pure" environment as evidenced that the country's population of 4.5 million supports 4000 conservation groups; however conservation is proportionally underinvested by governments (Seabrook-Davison and Brunton 2014), perhaps because the social and economic contexts are poorly understood by decisionmakers.

Environmental attitudes are strongly contingent on social context, and for PFNZ, the attitudes most at conflict pertain to the use of toxins for invasive mammal control. Because 1080 is the only currently available, cost-effective broad-spectrum toxin for landscape-scale control of invasive predators, its increased use has been recommended by the Parliamentary Commissioner for the Environment (PCE 2013). However, many people remain vehemently opposed to 1080, particularly against perceived "indiscriminate" aerial broadcast from helicopters, because of the collateral impacts on game animals and risks for dogs. Other broad-spectrum toxins—especially the second-generation anticoagulant brodifacoum—are the standard tools for eradicating pests permanently from islands. Brodifacoum and additional first-generation anticoagulants such as diphacinone, pindone, and coumatetralyl are in widespread use for rodent control in mainland homes, businesses and natural habitat fragments, but they may all have nontarget effects (Fisher et al. 2004).

Companion animals (cats and dogs), which are also predators of native biota, are notably excluded from the PFNZ concept. Although there is almost unanimous public support for the control of feral cats (Russell 2014), debate exists over the appropriate form of management for pet and stray cats; New Zealand has the highest rate of cat ownership in the world (NZCAC 2011). Conversely, advocates for PFNZ such as Gareth Morgan also argue for stronger enforceable legislation regarding cat ownership such as sterilization, registration, and microchipping; these advocates suggest that owners of cats do not replace pets after their death. These values-mediated issues are fundamental to conservation, and values-based debates are required, integrating contributions from biophysical and social scientists, economists, and conservation biologists if they are to yield effective policy. At the heart of these debates is the high value that people place on native biodiversity (Rogers et al. 2013).

Community support for PFNZ already exists and will provide the voter momentum required for long-term political commitment to develop relevant policies, independent of any current government. Coordination and prioritization will be required among the different government agencies tasked with predator management alongside privately funded and community efforts. Predator control activities would need to be accepted as part of daily life, which will require fostering intergenerational community support (Ban et al. 2013) and recognition that survival of New Zealand's native biota is central to a sense of national identity and an economy built around tourism and primary production.

Economic costs and benefits

Invasive predators threaten to undermine New Zealand's agriculture, horticulture, and forestry industries. For example, although rodents prefer cereals and seeds (which together accounted for over NZ$300 million in export earnings in 2013), these omnivorous generalists also feed on kiwifruit (NZ$934 million in exports), apples (NZ$475 million), other fruit (NZ$140 million), and vegetables (NZ$404 million). Possums eat an estimated 7.67 million tons of vegetation annually, including pine, eucalyptus, clover, and other economically important species. In addition, both possums and mustelids carry bovine tuberculosis, itself a target of national eradication (Livingstone et al. 2015), which causes stock losses, as well as threatening export markets for New Zealand's dairy (valued at NZ$12.2 billion in export earnings in 2013), beef (NZ$2.5 billion), and deer (NZ$192 million) industries.

Nimmo-Bell (2009) estimated that plant, vertebrate, and invertebrate pests cause NZ$1.44 billion in 2013 dollars in output losses annually. Some 98.8% of these losses accrue to terrestrial production and 68.1% stem from animals and invertebrates. Accounting for losses to upstream and downstream industries via the multiplier effect suggests that annual losses to primary industry from animal and invertebrate pests reach as much as NZ$1.83 billion in 2013 dollars, or 0.87% of GDP. Although national estimates of damages are not available for most species, Bertram (1999) estimates the economic damages caused by possums alone to be NZ$58.32 million in 2013 dollars.

Approximately 254,000 international visitors (i.e., roughly a quarter of all international visitors) participated in walking or hiking activities of one-half day or more during their visit to New Zealand (Tourism NZ 2014). There are few studies of the potential monetary impact of invasive predators on tourism; however, nascent evidence suggests that international tourists seek out predator-free areas. For example, Tiritiri Matangi, an island in the Hauraki Gulf, attracts approximately 14,000 international visitors and 23,000 domestic visitors per annum. The total number of visits has tripled since the island achieved its predator-free status in 1993 and is now capped by the Department of Conservation, resulting in people being turned away from the ferry at peak times of the year. Similarly, Ulva Island in Rakiura / Stewart Island's Paterson Inlet achieved pest-free status in 1997 and visits have at least doubled since. On the mainland, over 80,000 people visit the Zealandia predator-proof fenced ecosanctuary in suburban Wellington each year, 19,000 of whom come from abroad (Morgan and Simmons 2014).

Economists classify averted damages resulting from invasions and averted losses to tourism as the *benefits of eradication*. These direct and indirect monetary benefits of eradicating invasive predators are augmented by improved ecosystem services—that is, the benefits that people receive from ecosystems. Patterson and Cole (2013) estimate the net total value of New Zealand's land-based ecosystem services to be NZ$56.7 billion, and Morgan and Simmons (2014) noted that invasive predators impact provisioning services (e.g., timber supply), regulating services (e.g., biological control and carbon sequestration), supporting services (e.g., habitat for species), and cultural services (e.g., recreation, tourism, and sense of place). Although damage to ecosystem services caused by invasive predators have not been calculated for New Zealand as a whole, Morgan and Simmons (2014) estimated the net present value of enhancements to ecosystem services from predator control on 1746 km^2 Rakiura/Stewart Island to be NZ$125.9 million, more than four times the figure for tourism. They further note that benefits of control on New Zealand's mainland are likely to be substantially higher on a per-ha basis because of differing land uses and significantly higher population densities.

The cost of eradication varies widely across landscapes. For example, eradicating invasive predators from the 3820 ha Rangitoto-Motutapu islands in the Hauraki Gulf cost NZ$993 per ha in 2013 dollars (Griffiths 2011). For mainland ecosanctuaries control costs depend critically on methods: The net present cost of a fence to exclude all invasive predators from 1000 ha is estimated to be approximately NZ$646 per ha over a 50-year period whereas the net present cost of trapping over the same period is $224 per ha (Norbury et al. 2014). Beaven (2008) estimates the cost of eradicating invasive predators from Rakiura/Stewart Island to be between NZ$38.8 million and NZ$60.9 million in 2013 dollars, depending on the eradication method employed—that is, between NZ$210 and NZ$330 per ha. In contrast mainland control of invasive predators using aerially distributed toxins can cost as little as NZ$20 per ha.

Scaling these cost figures up to the whole of mainland New Zealand's 26.4 million ha yields total cost figures of between NZ$5.54 billion and NZ$26.22 billion in 2013 dollars. Assuming NZ$993 cost per ha (the highest per-ha cost of recent eradications), a 50-year campaign, a long-run inflation rate at the 25-year average of 2.55% and an 8% discount rate (the rate specified by the New Zealand Treasury for long-term investment projects) yields a total net present value of costs of NZ$9.04 billion. For comparative purposes, the net present value of current spending defending against all agricultural pests over the next 50 years is NZ$15.96 billion (Nimmo-Bell 2009), 55% of which is currently paid by the private sector.

With such limited data, calculating the total benefits of eradication is problematic. However, assuming that 25% of the NZ$1.83 billion in annual damages to crops and timber is attributable to invasive predators and that 33% of international tourists would spend one additional day visiting a PFNZ, the net present value of these averted losses total NZ$9.32 billion over 50 years, exceeding the upper-end estimates of the costs of achieving PFNZ even without considering the undoubtedly substantial benefits to ecosystem services. Because these net economic benefits accrue directly to the private sector, we anticipate that PFNZ will enjoy the support of the primary industry and the tourism industry.

Conclusions

A 50-year time frame has emerged for the aspirational goal of PFNZ, coinciding with the increased scale of island eradications. The first step would be to set national targets for the percentage area that is pest-free, benchmarked against international standards (e.g., 10% pest-free offshore island estate). Eradication of invasive predators from the two largest offshore islands: Rakiura/Stewart Island (174,600 ha) and Aotea/Great Barrier Island (27,761 ha) has therefore been proposed as an interim 10-year target. This would increase New Zealand's invasive-mammal-free offshore island area to over 50%. Eradication of invasive predators and maintenance of predator-free status on these two large islands inhabited by humans would demonstrate proof of concept for scaling to the New Zealand mainland. Simultaneously, mammal-free peninsulas have been advocated as a stepping stone to achieving local eradications. Following this, more large (i.e., larger than 100,000 ha) ecosanctuary reserves are proposed, providing connectivity of halos across landscapes. This would require defining an accredited minimum standard in pest control that achieves biodiversity outcomes.

These large ideas build on the thousands of scattered, small-scale pest control efforts already underway in neighborhoods, catchments, and sanctuaries. Counterintuitively, large urban areas might have head starts as pest control hubs, with more volunteers, fewer pests and limited pest habitat (Morgan et al. 2009). Within decades, the concepts of pest eradication and sustained control across all initiatives would merge. Addressing the challenges will require the integration of pest control research activities with wider biological, social, and economic considerations. Ecologists will need to step well outside their traditional boundaries and work with social scientists, economists, and policymakers to deliver the required pest management solutions (Allen et al. 2014). The economic case for PFNZ is already compelling, but at the core of the process is a bottom-up driven approach to community engagement in conservation, so that as new technologies become available, the number and size of invasive-mammal-free publicly and privately managed reserves can increase. Clearing predators from all of New Zealand may seem to be a fantasy, but 50 years ago, so did clearing predators from tiny, 1-ha Maria Island. With the right tools and social investment, history has shown what transformations can be achieved. We would be foolish not to imagine what can be achieved 50 years from now.

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