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REVIEW

Small mice create big problems: Why Predator Free New Zealand should include house mice and other pest species

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Abstract
Predator Free 2050 (PF2050) is a government initiative aiming to eradicate selected invasive mammals (mustelids, rats, and possums) from New Zealand (NZ) by 2050. Selecting which of 32 introduced mammal species to include has received little evaluation, yet targeting a few species often results in perverse ecological outcomes given interactions within the invasive guild. We explore how PF2050 could be improved strategically by focusing on biodiversity outcomes instead of selectively targeting invasives, using rodents as an example. Current PF2050 targets include all rat species (*Rattus exulans*, *R. norvegicus*, and *R. rattus*), but not the house mouse (*Mus musculus*). Mice can be as damaging as rats when competition and predation are removed, negating benefits of rat removal. Multirodent eradications are more cost-effective and prevent mesopredator release. Using a case study, we show adding mice to a rat eradication would raise costs modestly, comparing favorably to independent mouse eradication later, which would be riskier and more socially and economically costly than the preceding rat eradication. Missing the opportunity to tackle all rodents simultaneously, leaving mice to multiply in numbers and impacts, could have serious environmental and socioeconomic consequences. Naïve eradication strategies neglecting ecological expertise risk biodiversity outcomes and NZ's eradication science reputation.

KEYWORDS
ecology, invasive species management, landscape ecological restoration, multispecies eradication, *Mus musculus*, rodent

1 | INTRODUCTION

Aotearoa New Zealand (NZ) faces a biodiversity crisis. At least 63 native species have become extinct since the arrival of humans, and 4374 species are threatened or at risk of extinction according to the NZ Threat Classification System (https://nztcs.org.nz/). The causes are multifactorial; however, being an insular country with no native terrestrial mammals apart from bats, the introduction of invasive mammals has been particularly devastating (Clout, 2001). There are 32 species of introduced mammals in the wild in NZ (King & Forsyth, 2021), with diverse size (from rodents to ungulates), habits (terrestrial to arboreal), and diets (herbivorous, omnivorous, and carnivorous), of which 14 species are widespread (Tables S1 and S2). In addition to the ecological damage caused, some invasives (e.g., Australian brushtail possum *Trichosurus vulpecula* and domestic cat *Felis catus*) have profound impacts on agriculture and human and livestock health (Clout, 2001).

Active management of established pests has two approaches: eradication or control. Eradication involves complete removal of the target population in a discrete time interval; control aims to suppress the number of pests to a target level and is done recurrently and in perpetuity (Bomford & O'Brien, 1995). Eradication techniques pioneered in NZ are now a major restoration tool on islands worldwide (Spatz et al., 2022). In NZ, 117 offshore islands have been cleared of invasive mammals (Russell & Broome, 2016), with strong outcomes for ecosystem recovery (Towns, 2011; Prior et al., 2018). In addition to true geographical islands, ring-fenced ecosanctuaries (Innes et al., 2019) created with predator-resistant fences have also benefited from mammal eradications, although mouse reinvasion limits ecological recovery in some ecosanctuaries (Watts et al., 2022). On the North and South Islands (hereafter mainland NZ), control programs are implemented to reduce impacts of invasive mammals on threatened species and ecosystems (Innes et al., 2023). Sustained effort is key to sustaining benefits; thus, it is socially, environmentally, and financially costly in the long term. Further, resources are insufficient to treat all areas.

The Predator Free 2050 (PF2050) initiative was launched by the NZ government in 2016 to eradicate mustelids (*Mustela* spp.), rats (*Rattus* spp.), and possums from mainland NZ by the year 2050 (Russell et al., 2015). PF2050 funds large-scale control and eradication trials, and development of potential new tools. However, PF2050 has been criticized for shortfalls in eradication technology, insufficient finance, low scalability of existing tools, and inadequate consideration of social and ecological complexity, each of which erodes viability of the initiative (King, 2023; Leathwick & Byrom, 2023; Linklater & Steer, 2018; Monks et al., 2023; Parkes et al., 2017; Peltzer et al., 2019). National biosecurity, that is, safeguarding from repeated international pest invasions, for example, has not been assessed despite being a prerequisite for eradication (Kennedy & Broome, 2019), and NZ's ability to manage pest reinvasions locally and regionally remains questionable (Barron et al., 2023). Between 2016/17 and 2020/21 NZ$306.28 million has been spent under the Predator Free umbrella, mostly on pest control which reduces to NZ$212.28 million if investments in habitat restoration and targeted biodiversity protection are subtracted (DOC, 2021). Investment in focused and strategically led eradication exemplars is a very small aspect of the overall investment. The national strategy (DOC, 2020) does not address basic criteria for feasibility of eradication (Bomford & O'Brien, 1995; Peltzer et al., 2019). We argue that all eradication exemplars should do so, in order to increase viability of the national goal. This and many other strategic improvements are required. We explore these wider strategic shortcomings using rodents as an example.

Four species of invasive rodents are present in NZ. Pacific rat or kiore *(Rattus exulans)* arrived first with Polynesian settlers in the early 13th century; they have ongoing impacts on native flora and fauna that did not evolve with rats (Towns, 2009). Norway rats (*R. norvegicus*) arrived during the 18th century on European ships, and house mice (*Mus musculus*; hereafter mouse or mice) and ship rats (*R. rattus*) a century later (Veale et al., 2018). Since introduction to NZ, mice became more ecologically widespread than in Eurasia because they encountered fewer competitors and predators (Murphy & Nathan, 2021). Mouse distribution and abundance are influenced by the presence of larger, dominant predators and competitors, for example, rats and stoats (*Mustela erminea*) (Watts et al., 2022). PF2050 targets all three rat species, but not mice (DOC, 2020; Tompkins, 2018). Such reductionist management often has perverse ecological outcomes given complex interactions among species; foreseeing such responses should be embedded in any eradication strategy (Glen et al., 2013; Zavaleta et al., 2001), but particularly for PF2050 (Peltzer et al., 2019). Moreover, because mouse impacts can be as dramatic as rat impacts, mice and rats are routinely targeted simultaneously in control programs and island rodent eradications (see below).

It is not clear why mice were excluded from the PF2050 goal. Beyond a small survey of 19 stakeholders (Tompkins, 2018), there is no published account of the process by which possums, rats, and mustelids were chosen. For example, while kiore are included in the goal, this species has localized ecological effects and has cultural significance in some areas (Towns, 2009), whereas mice arguably have a more significant impact at a national scale, a concern that was noted by ecosanctuary survey participants at the time. A robust analysis of the species for inclusion in such a significant national initiative could have considered multidimensional political, social (Liang, 2023), cultural, and financial aspects of the campaign as well as the practical aspects of planning for eradication, ensuring that the consequences of eradicating select species are evaluated.

Indeed, a major criticism of the PF2050 campaign to date is that desired outcomes for biodiversity have not been clearly articulated (Leathwick & Byrom, 2023; Innes et al., 2023). Given the known impacts of mice on NZ's native flora and fauna, their impacts on biodiversity loss globally, and their propensity for mesopredator release

TABLE 1 Completed and planned house mouse eradications on islands >10 km^2.

Island	Country	Size (km^2)	Other target rodents?	Other target mammals?	Eradication date	Reference
COMPLETED						
South Georgia[a,b]	UK	3528	Yes	No	2011–2015	Martin & Richardson (2017)
Macquarie	Australia	129	Yes	Yes	2011	Springer (2018)
Rangitoto-Motutapu[c]	NZ	38	Yes	Yes	2009	Griffiths et al. (2015)
Antipodes	NZ	20	No*	No*	2016	Horn et al. (2019)
Lord Howe[c]	Australia	15	Yes	Yes	2019	Harper et al. (2020)
Te Puka-Hereka (Coal)	NZ	12	No*	Yes	2008	Broome et al. (2019)
PLANNED						
Auckland	NZ	445	No*	Yes	TBD	Horn et al. (2022)
Marion[b]	SA	300	No*	No*	2026	Connan et al. (2023)
Guadalupe[c]	Mexico	242	No*	Yes	TBD	GECI (2021)
Floreana[c]	Ecuador	170	Yes	Yes	2023	Island Conservation (2020)

[a]Eradicated area was 1068 km^2 (the rest were rodent-free glaciers).
[b]Research station only.
[c]Inhabited island.
*Only mice present.
TBD, to be determined; NZ, New Zealand; SA, South Africa; UK, United Kingdom.

(see below), this is a major oversight and an opportunity missed. We argue that focusing on the desired outcomes for biodiversity (part of any feasibility study as recommended by eradication best practice) would have clearly highlighted mice as a potentially significant issue to address in the PF2050 campaign. Moreover, the exclusion of mice highlights how a focus on top-down control and eradication methods is often employed without reference to the potentially stronger bottom-up effects of resource availability (King, 2023). Mice are a driving component of stoat diets (White & King, 2006), so removal of mice (as a primary prey of stoats) is likely to be a critical component of the eventual eradication of that species (by reducing primary food resource availability and hence stoat survival), especially considering limitations of current and near-future tools. Targeting mice alongside rats within the PF2050 context is an extraordinary opportunity in ecological, financial, and social terms, capitalizing on the advantages of multispecies eradication strategies, particularly given the same eradication approach is commonly used for all rodents (Howald et al., 2007; Table 1). Below, we outline current knowledge on impacts of mice in global and national contexts, providing insights from recent research. We then discuss the prospects of eradicating mice or controlling them in perpetuity, and lessons from global island rodent eradications. Finally, a case study illustrates how expanding rat eradication to all-rodent eradication compares favorably financially, augmenting social and ecological benefits.

2 | HOUSE MOUSE IMPACTS

2.1 | Global impacts

Mice, with a global distribution second only to humans, are a major threat to biodiversity, economies and human health, hence their inclusion on the IUCN's list "100 of the world's worst invasive species" (Lowe et al., 2000). As opportunistic omnivores, mice directly and indirectly impact natural systems via consumption of seeds, plants, and a wide range of animals, often consuming proportionally more animal than plant matter (Shiels & Pitt, 2014). Known for their preference for invertebrates, mouse predation can have profound consequences given the crucial roles of invertebrates in ecosystem functioning, for example, pollination (St Clair, 2011). Moreover, where mice have depleted available invertebrates, they often exploit larger prey such as seabirds (Caravaggi et al., 2019). Indeed, dramatic examples come from islands where mice are either the only introduced mammal or the only species not yet eradicated (Angel et al., 2009). For example, on Gough Island an estimated 2 million eggs and chicks are preyed on by mice annually (Caravaggi et al., 2019); a 2021 eradication attempt yielded dramatic increases in 2022 hatching success for several species of seabirds (RSPB, 2022). On Marion Island, early signs of mouse attacks on seabirds were recorded in 2003, 12 years after cats were eradicated; today mice regularly attack and kill seabird chicks and adults (Connan et al., 2023). Similarly, on Midway Atoll mice were first recorded attacking seabirds in 2015, 19 years after ship rat eradication (Duhr et al., 2019). Collectively, these reports emphasize the remarkably short timeframes within which mice can change diet, and that novel ecological impacts play out years after removal of predators or competitors.

Mice also impact human systems (Nghiem et al., 2013). Their impacts on agriculture are well known globally; crop consumption and contamination of storage areas and facilities translate to multimillion-dollar losses (Stenseth et al., 2003). In Australia, mouse plagues have become a regular feature in grain-producing regions over several decades, with densities reaching a staggering 2716 mice/ha (Singleton et al., 2007). The advent of "conservation agriculture" in Australia, which is more environmentally sensitive and economically viable, may generate higher mouse populations via less disturbance of burrows and increased cover and food supply, necessitating new pest management frameworks (Ruscoe et al., 2021). Mouse impacts on food security are linked to global warming and climate instability (Singleton et al., 2010), with impacts expected to worsen.

Mice exacerbate human stress and fear (Randler et al., 2012) and are also vectors and reservoirs of human and livestock pathogens, transmitting viral, bacterial, rickettsial, and parasitic diseases, including toxoplasmosis, leptospirosis, salmonellosis, and campylobacteriosis, as well as endo- and ectoparasites such as tapeworms and fleas (Blackwell, 1981; Charrel & de Lamballerie, 2010). Among commensal rodents, mice are typically closest to humans in both urban and rural environments: multiple pathogenic bacteria associated with human diseases have been found in mice (Williams et al., 2018).

2.2 | New Zealand impacts

The abundance of mice in NZ is predictably variable. Studies describe a range of densities with a maximum of 157 mice/ha in a fenced ecosanctuary where other mammals had been eradicated (Goldwater, 2007). In native forest ecosystems, mouse populations are driven by seed production (King, 1983). Dominant tree species in these forests exhibit synchronized seeding (masting) events that often produce dramatic increases in population densities (Ruscoe et al., 2005). Similar relationships occur in mid-to high-altitude native grassland ecosystems, where abundance of invertebrates and lizards is inversely related to mouse abundance (Norbury et al., 2023).

Mouse diets in NZ are varied but dominated by plants and invertebrates (Murphy & Nathan, 2021). Evidence of mice as predators of larger and sometimes threatened prey in NZ first emerged in the 1970s. A study of mouse ecology on Mana Island, where mice were the only mammalian predator, found that mice ate native lizards, with skinks comprising up to 20% of the diet (Bellingham, 1990). Mouse eradication on Mana enabled the threatened MacGregor's skink (*Oligosoma macgregori*), goldstripe gecko (*Woodworthia chrysosiretica*), and Cook Strait giant weta (*Deinacrida rugosa*) to recover (Newman, 1994). Emerging NZ evidence suggests mice can not only suppress invertebrate populations but also influence their body size (Watts et al., 2022).

While impacts on threatened taxa are generally cryptic and unreported, mice have been recorded preying on large (>25 cm length) threatened skinks, causing a strong decline in survival compared to a population protected from mice (Norbury et al., 2014). Mice also prey on other threatened lizards and birds (Michelsen-Heath & Gaze, 2007). Despite these reports, most mouse impacts on biodiversity in NZ remain unknown, as threatened species are neither monitored in tandem with invasive predator dynamics nor with sufficient frequency and resolution to clarify the relationship.

Climate change also has potential to exacerbate mouse impacts in natural and agricultural ecosystems in NZ (Holland et al., 2015). Should agricultural practices change in favor of either arable or greater sustained vegetation cover, farmers could anticipate increased mouse abundance and impacts, as in Australia (Ruscoe et al., 2021). Any increase in distribution and abundance of mice has implications for agriculture and human health in NZ given demonstrated links between mice and zoonotic infections of public health concern (Morand et al., 2015).

3 | MANAGEMENT CONSIDERATIONS

3.1 | Mice in the absence of predators and competitors

Ring- and peninsula-fenced ecosanctuaries provide experimental arenas to assess how mice respond to removal of other mammalian predators because of their ability to reinvade these ecosanctuaries (Watts et al., 2022). In Tawharanui Open Sanctuary, mouse population indices increased from zero prior to eradication (of all other invasive mammals) to more than 180 mice/100 trap nights (Goldwater et al., 2012). Mouse body mass at Tawharanui also increased over time, suggesting that mice in NZ (usually < 25 g) potentially respond similarly to mice on some subantarctic islands where maximum mouse mass (in the absence of other mammals) surpasses the 50 g mark (Goldwater et al., 2012; Jones et al., 2003). Whether this increase in body size observed in NZ is driven by greater life expectancy following removal of predators, or resultant from rapid natural selection for larger individuals due to mesopredator release, has not been determined. Considering that on subantarctic islands mice prey on seabirds 300 times their body mass (Cuthbert & Hilton, 2004), it is reasonable to expect dramatic shifts in the predator-prey ecology of mice post-PF2050 (Norbury et al., 2023). Would mouse control in the absence of predators and competitors be sufficient to maintain their ecological impacts at or below current levels? Notwithstanding the fact that we currently lack mouse control tools that are suitable for sustained and high frequency use, it would certainly be more difficult and costly than at present, as mice are likely to expand ecological niches (for example, climb more; Innes et al., 2018), and in doing so achieve higher densities (Goldwater et al., 2012). Even in circumstances where competitors such as rats are only being controlled as opposed to eradicated, mesopredator release in mice has been observed, resulting in the suppression of native lizards (Monks et al., 2023).

Mouse populations are largely bottom-up regulated by food availability (Choquenot & Ruscoe, 2000), so food resources (and nesting habitat) would likely increase if competitors are removed, enabling exploitation of previously unavailable resources (Bridgman et al., 2018). For example, mouse densities reach 50/ha on mainland NZ with other predatory mammals present (Ruscoe, 2001). In contrast, densities after mammal eradications in NZ have increased to > 150 mice/ha (Goldwater, 2007). On islands where mice lack competitors and predators, densities of > 1000 mice/ha have been recorded (Polito et al., 2022). In dry agricultural areas of Australia, despite a diverse assemblage of potential predators of mice, densities have been documented at 2716/ha (Singleton et al., 2007), illustrating the degree to which dynamics are bottom-up (cf. top-down) driven.

3.2 | Mouse eradications

Only recently have mice received increasing attention by conservationists. Angel et al. (2009) suggested two reasons for this: scant knowledge of described impacts on charismatic fauna and perceived higher failure rates for mouse eradications compared to rat eradications. Both appear to be the result of mice being understudied and therefore underestimated for decades (see above), and not being explicitly targeted (or even detected) during early rat eradications (Broome et al., 2019). Indeed, many rodent eradication failures are explained by human error, which once corrected often result in eradication success (Samaniego et al., 2021). Fine-tuning best practice for mice was key to improving this track record, questioning the mindset that “mice are too difficult to eradicate” (Broome et al., 2019).

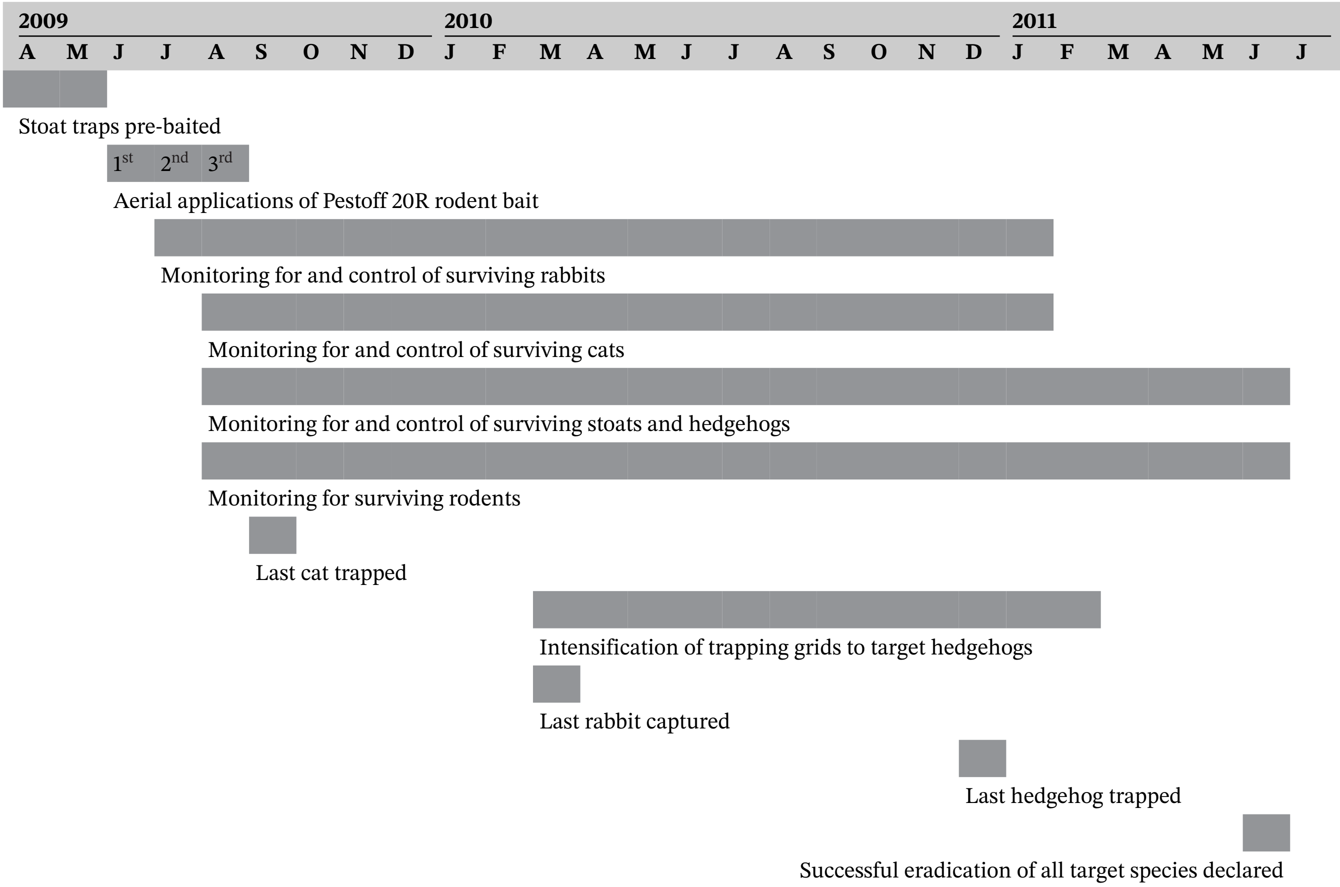
Up to 2019, mice had been eradicated from 59 islands worldwide, including 28 NZ islands (Broome et al., 2019). Encouraged by this trend, mouse eradications on large islands, some inhabited, are being planned, either targeting only mice (where no other mammals are present) or as part of multispecies eradications (Table 2). Despite ever-increasing island size and complexity, the eradication success rate for mice has increased notably (Spatz et al., 2022) and has been higher than for rat eradications since 2005 (Samaniego et al., 2021). Conversely, pest-fenced, mainland ecosanctuaries have recurrent issues managing mice, perhaps due to small juvenile mice passing through the fence, although confirming that reinvasion rather than incomplete eradication is the main cause requires mark-recapture studies (Goldwater et al., 2012; Innes et al., 2019). Once inside, mice breed rapidly and become abundant because their usual predators and competitors are missing; at Maungatautari (central North Island), mice removed about half of the litter invertebrates, probably to the detriment of native fauna relying on this resource (Watts et al., 2022).

NZ researchers have recently begun addressing management of mice (Hitchmough et al., 2016), highlighting a limited understanding of mouse ecology and limitations of existing control tools to protect threatened species and ecosystems. One driver of this limitation is the extreme paucity of funding for developing control tools for non-Predator Free pest predators, due in part to diversion of a significant proportion of Department of Conservation (DOC; the NZ government agency responsible for managing biodiversity on public lands) funds into PF2050 associated work (DOC, 2021). Other than improved mammal-resistant fences, there are currently no approved tools for large-scale, long-term mouse control with acceptable flow-on effects for mainland NZ, as brodifacoum (the most effective rodenticide for mice) is biopersistent (Howald et al., 2007) and its use is highly restricted. One aim of PF2050 was to incentivize investment in new tools and innovations for pest eradications at scale, which provides a compelling argument for inclusion of mice as part of any multispecies eradication campaign.

3.3 | Multispecies eradications

Eradicating mice and rats simultaneously is a logical approach because it is cost-effective, less socially taxing (as every human structure needs treatment), and the only way of avoiding the documented undesired flow-on effects of removing rats only (Innes et al., 2023). In fact, all global records for mouse eradications are examples of multispecies eradications (Table 1). The largest uninhabited island cleared of mice is Macquarie (128 km^2); the largest inhabited island is Lord Howe (14.5 km^2) (Table 1). South

TABLE 2 Timeline for the successful Rangitoto-Motutapu multispecies eradication, showing the efficient sequencing while targeting eight species of invasive mammals (including four rodent species) in a single operation.



Source: Simplified from table 1 in Griffiths et al. (2015).

Georgia Island (3528 km^2) is usually excluded from global statistics because it was not a standard rodent eradication (baiting done in phases, with large glaciers excluded from treatment); however, both rats and mice were eradicated from the 1068 km^2 rodent-occupied part of the island (Martin & Richardson, 2017), an order of magnitude larger than Macquarie Island. Ongoing planning for Auckland Island (460 km^2) targets all invasive mammals (mice, cats, and pigs *Sus scrofa*), because "*Eradicating all three target species is the only way to fully realise the benefits and avoid detrimental trophic shift responses*" (Horn et al., 2022). These are the same reasons why the projects in Table 1 never considered excluding mice from their eradication operations.

When mice are not eradicated alongside rats and other invasive predators, mouse populations increase and disperse at best, and also change diet and habits resulting in rat-like impacts at worst—lessons learned from early, selective eradications (e.g., cases in Veitch et al., 2019 and previous editions). These lessons prompted subsequent eradication operations to remedy mouse impacts, incurring additional costs and risks to nontarget species with repeated toxin use (given aerial baiting using rodenticides is the preferred eradication method for any invasive rodent; Howald et al., 2007).

Biosecurity measures to prevent or limit reinvasion by mice after eradication are similar to those for rats and mustelids; prevention of arrival is vastly preferable and more cost-efficient than searching for reinvaders (Kennedy & Broome, 2019). A variety of detection devices and tools must be distributed widely in likely habitat (within and outside eradication zones) and maintained with fresh lure. Trained rodent dogs detect both rats and mice (Gsell et al., 2010), and genetic tools can be used to query if individuals are survivors or reinvaders (depending on genetic diversity). Unmanaged, mice interfere with monitoring devices set for other species, removing bait and triggering devices including cameras, increasing costs and compromising rapid detection and elimination of rats (Wilson et al., 2018).

4 | CASE STUDY

We used the successful island eradication from Rangitoto-Motutapu, NZ, to retrospectively compare cost and operational differences between the implemented multispecies eradication and theoretical scenarios targeting rats and mice in separate operations. The brief descriptions of the islands and the eradication operation are based on Griffiths et al. (2015).

The Rangitoto-Motutapu complex (two islands artificially connected) is 3 km offshore from the largest city (Auckland) in NZ. Rangitoto is forested and Motutapu is dominated by pastoral farmland with areas of regenerating forest and wetlands. In 2009, rodents (all three rat species and mice) were eradicated from the island complex (3842 ha) at the start of a multispecies eradication operation, which also eradicated cats, rabbits (*Oryctolagus cuniculus*), hedgehogs (*Erinaceus europaeus*), and stoats, that is, all eight species of invasive mammals present (Table 2). The main rodent eradication method was the aerial application of brodifacoum bait, with nearly 1000 bait stations inside buildings as a complementary method. Rangitoto-Motutapu are representative of mainland NZ in that they include native forest, farmland, and human-made structures, along with a common suite of introduced predators including rats and mice. On Motutapu, farming operations were suspended during the eradication operation and stock were removed from the island for approximately four months.

Although the efficiencies and savings of eradicating all rodent species simultaneously were clear from the planning process (Griffiths et al., 2015), there were, in theory, three potential management scenarios: (1) rat eradication, (2) rodent (rat and mouse) eradication, and (3) two separate eradications (rat, then mouse when deemed necessary) (Table 3). A rat eradication, ignoring mice, would resemble the current PF2050 approach; however, it was never considered a viable option despite potential savings of 22.5% (Table 3), mainly because leaving mice behind would negate benefits of rat eradication, and biosecurity for rats would be extremely difficult and costly with mice present, eventually negating initial savings. Instead, a rodent (rat and mouse) eradication was implemented given that moderate operational and cost increases (Table 3) were expected to yield vastly better long-term social, economic, and environmental outcomes. In practice, this meant implementing similar procedures (as for rat eradication) to the highest standard, and carrying out a third bait drop (which also targeted the larger target species). Finally, under Scenario 3 (separate, independent eradications), a subsequent mouse eradication would have faced higher operational risk and been more expensive and more socially taxing than the preceding rat eradication, as mice are expected to be more abundant after rat removal. We estimate this approach would have raised the cost of clearing all rodents by about 77% (Table 3). Indeed, Griffiths et al. (2015) noted that "*When compared to other projects that targeted the same* [eight] *species but individually, we estimate the Rangitoto and Motutapu project to have cost less than 50% of the total potential cost if each species had been removed in a discrete operation. Logistical efficiencies created by condensing several operations into one and the use of eradication and detection techniques that targeted multiple species are credited as having the greatest influence on the increased efficiencies observed.*"

We identified four risk categories in separating rat and mouse eradications (Scenario 3).

Financial

Costs for planning and preparing aerial toxin applications average 69% (11%–142%, $n = 11$) of the implementation costs (Holmes et al., 2015), which would occur twice (years to decades apart) under Scenario 3. Likewise, recruitment and training of field staff, which is expensive due to the specialist expertise required, would need to be repeated. Infrastructure and communication investments (e.g., offices, vehicles, IT, GIS) are also lost between eradications under Scenario 3 as in New Zealand such investments are often rapidly redeployed for other uses. Biosecurity costs after rat eradication would also increase significantly as a result of interference by mice.

Technical

Mice, even at low density, interfere with bait, traps, and detection devices, which complicates rat eradication and compromises post-rat-eradication biosecurity monitoring. Rat biosecurity protocols in the presence of mice would need to account for frequent mistaken reports of "rats" constantly triggering costly incursion responses by highly experienced staff (to discern between rat and mouse sign).

Social

Independent eradications require significantly more toxin, with repeated, prolonged site access and restrictions on human activities. Farming activities, for example, would cease twice under Scenario 3. This poses a risk to the challenging acquisition of social license and permissions to access private properties and would increase the duration of risk to domestic pets. Stakeholders would be disappointed if outcomes of the rat eradication do not meet expectations due to subsequent mouse impacts on livelihoods and wildlife. Lost trust and toxin aversion could thus impede or compromise a second eradication.

Environmental

On Rangitoto-Motutapu, 147 tons of brodifacoum bait were used. The amount of bait required would at least double

TABLE 3 Indicative comparison of risks and impacts of eradication scenarios of our Case Study.

Category Item	Scenario 1 rat eradication (ignoring mice)	Scenario 2 rodent (rat and mouse) eradication	Scenario 3 independent rat and mouse eradication
	Current PF2050 approach	Implemented approach, maximizing outcomes	Rat eradication first, mouse eradication years later
Financial			
Infrastructure investment (e.g., vehicles, buildings, storage, IT, GIS)	Once	Once	Twice
Planning, permissions & PR	Once	Once	Twice
Recruitment & training	Once	Once	Twice
Implementation time	3 months	3 months	3 months + 3 months, years later
Total rounded costs (NZD)	1,420,000	1,830,000	3,250,000
Total costs per ha (NZD)	370	477	846
Cost difference from actual (%)	−22.5	actual	+77
Technical			
Mouse interference with bait, traps and detection devices during and after eradication	Ongoing	Avoided	Ongoing until mouse eradication
Anticoagulant resistance in rodents by prolonged exposure	Ongoing (in mice)	Avoided	Ongoing until mouse eradication
Social			
Social license and public support	Once	Once	Twice
Negative impact on well-being, properties, pets, livestock	Ongoing (from mice)	Avoided	Ongoing until mouse eradication
Environmental			
Rodenticide contamination	Ongoing (through mouse control)	Avoided	Ongoing until mouse eradication
Predation on/competition with native species	Ongoing (from mice)	Avoided	Ongoing until mouse eradication
Biodiversity and social gains	Limited	Maximized	Limited until mouse eradication

Note: Costs estimated for Scenarios 1 and 3 are based on actual costs of Scenario 2 as implemented for the Rangitoto-Motutapu eradication (Griffiths et al., 2015).

under Scenario 3, increasing significantly the risk of primary and secondary poisoning of native and introduced nontarget species (e.g., pets). Biodiversity outcomes after rat, but before mouse, eradication can be negligible (Duhr et al., 2019).

5 | DISCUSSION

Our aim was to examine the strategic shortcomings of a laudable national conservation goal: Predator Free 2050 in NZ. Invasive rodents are a case in point for the PF2050 campaign, acknowledging other taxa warrant equal attention. Focusing on the desired outcomes for biodiversity would have—right from the inception of the campaign—shone a spotlight on mice as a key threatening process for NZ's native taxa. By highlighting the lack of inclusion of mice in PF2050, and demonstrating how cost-effective their inclusion would be, we have suggested how PF2050 could be improved strategically. Doing so would give more explicit consideration to the wider ecosystem implications, including biodiversity outcomes, instead of selectively targeting invasives. PF2050 undoubtedly must be improved, and what is needed, both at the outset and on an ongoing basis, is a robust assessment of feasibility, assumptions, biodiversity goals, current results, and delivery of outcomes. This observation is relevant to eradication attempts worldwide. Published recommendations on species removal in a whole-ecosystem context have been available for over 20 years (e.g., Zavaleta et al., 2001).

In addition to having the potential to undo many environmental benefits of removing larger invasive mammals, a reductionist approach can also make subsequent control or eradication of other invasives more difficult if social license needs to be relitigated. The consequences for human health and well-being, primary industries, and the total financial cost, can be significant. These consequences highlight an obligation—particularly when spending public funds—to engage stakeholders early in the process, and to update and refine approaches in real time as shortcomings are revealed and as new information becomes available (Towns, 2011).

Based on our literature review and case study, we have four recommendations.

First, *improve leadership*. Our assessment has highlighted the important leadership role that national biodiversity agencies should play both in determining conservation goals and in monitoring progress toward achieving them. The Department of Conservation currently has responsibility for much of NZ's biodiversity management, and their leadership is vital in applying existing prioritization systems and eradication expertise, managing prioritization conflicts between eradication and other strategies, formally planning and monitoring pest and biodiversity abundance to agreed national standards, and even ensuring that eradication terminology is universally understood across multiple stakeholder groups.

Second, *correct the approach*. It is vital to instigate an outcomes-driven conservation approach to PF2050 and similar large-scale eradications of invasive species globally (i.e., management of all key pressures to achieve clearly defined ecological outcomes), with robust, detailed and ecologically informed consideration of how different pests—including mice—should be targeted across landscapes. Measurement of biodiversity and other outcomes should be prioritized ahead of body counts of mammal predators. The current focus on "predators" has resulted in little to no research or operational focus on how ecosystems are impacted by nontarget pests (e.g., ungulates, pigs, cats, dogs, hedgehogs—and mice, not to mention other biotic threats such as plant pathogens and invasive invertebrates). Focusing solely on the eradication of a subset of pests in the long term, at the cost of addressing threatened species and ecosystem needs in the short-term, places vulnerable biodiversity at unacceptable risk of loss. A critical lesson is that selection of target pests should be appropriate to the biodiversity gains being sought.

Third, *reevaluate species to target*. Mice (among other species) should be considered for inclusion as an explicit PF2050 target species where biodiversity benefits can be expected, aiming for their eradication alongside rats. Large-scale projects on mainland NZ, particularly around urban areas, require new tools that can address such scales and realities, whether a single- or multispecies eradication is implemented. For islands where current tools can be applied, adding mice as an explicit target species for PF2050 requires extra upfront planning, effort, and funding (varying regionally according to site complexity, inhabitation, and techniques used). However, past multispecies operations (e.g., our case study) have confirmed that such scenarios are preferable when compared to the alternative: two or more higher-risk separate eradications costing potentially >100% extra. Aerial eradications are more cost-efficient; ground operations (e.g., in urban areas) are more expensive and carry higher operational risks. However, effective biosecurity must be resolved and funded prior to embarking on eradication if potential successes are to be sustained (Kennedy & Broome, 2019). We acknowledge that including mice would not be without risk: rodent eradication campaigns that include mice require implementation to the highest standard and can be more protracted, and detecting and managing reinvaders require extra effort. However, similar biosecurity issues already exist for rat eradications and could be addressed with relatively minor modifications to include mice, which would make monitoring easier and cheaper in the long term.

Finally, *engage with eradication experts*. It is critical that NZ incorporates invasion science expertise and knowledge into PF2050. Such expertise and established standards of eradication—including robust feasibility planning and review—have been essential steps in past successful eradications and have been globally recognized in the form of internationally sought feasibility and operational reviews from the Department of Conservation's Island Eradication Advisory Group (Brown et al., 2023; Cromarty et al., 2002). With such recognition comes a responsibility to ensure that national goals are informed by robust, scientifically sound expertise, and such expertise should have been involved early in the planning of the PF2050 campaign. As a recognized leader in pest eradications, NZ will influence global pest management with decisions made in tackling ambitious conservation goals like PF2050. Naïve eradication strategies that neglect ecological expertise risk failing to achieve biodiversity outcomes and compromise NZ's eradication science reputation.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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