Manaaki Whenua
Landcare Research

Insights paper: analysis of the target pest species for Predator Free 2050

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Summary

Project and client

- Predator Free 2050 (PF2050) is a national programme to eradicate brushtail possums, three mustelid species, and three rat species from New Zealand by 2050.
- In anticipation of programme roll-out by 2030, the Department of Conservation (DOC) commissioned Manaaki Whenua – Landcare Research to review whether the species target list should change to ensure wider ecosystem outcomes.

Methods

- We used published scientific evidence and expert opinion to evaluate each species on the current target list (plus feral cats, hedgehogs, and mice) against a standardised set of criteria: current impacts, ecological risks, socio-political risks, and feasibility of eradication. We also identified key knowledge gaps where the focus on research and innovation should be applied.

Review findings

- Clearly, eradicating all of the above 10 pest species will achieve wider ecosystem outcomes than eradicating a subset, but identifying which of these species are critical agents of biodiversity decline, and the easiest to eradicate, provides an opportunity to refine the target list.
- Unfortunately, there is considerable difficulty identifying which species are the most critical agents of decline and predicting national outcomes of their eradication, because of:
  - huge variation in pest impacts between sites, due to varying predator and prey abundances and habitat quality
  - inability to narrow down species-specific impacts based on the results of multi-species pest control
  - significant bias in the published evidence of pest impacts on indigenous species.
- Similarly, it is difficult to assess the ecological risk of meso-predator release of ship rats (following possum, mustelid, or cat control) or mice (following ship rat, mustelid, or cat control) because it depends on food availability. There is a lack of understanding of *net outcomes* of these interactions for indigenous species, making it difficult to assign ecological risk from the removal of a given pest species or a sub-set of species present in an area. What, for example, is the net outcome when ship rats are removed and mice increase? Mice potentially pose a significant risk to biodiversity recovery, but it depends on the indigenous species or ecosystem services we wish to protect.

- We conducted a high-level assessment of the feasibility of eradicating each species from the New Zealand mainland using current technologies, and concluded that eradication is:
  - plausible for possums and perhaps ferrets
  - beyond current capability for mice, weasels, stoats, feral cats, hedgehogs, Norway rats, and ship rats (in increasing order of potential feasibility)
  - complex and indeterminate for kiore.
- Kiore are widespread throughout the Pacific and Southeast Asia but are genetically similar within New Zealand. They are significant to many tangata whenua, particularly Ngātiwai, because they have a shared history of migration to New Zealand, and some consider kiore are part of their whakapapa and/or traditional practices. To others, even within a rohe, they represent a risk to other valued species and environments. Their impacts on islands, for example, can be significant. While arriving at co-management solutions risks being overly complex, the limited distribution of kiore populations nationally means that a rohe-based approach to whether kiore are a target species is feasible for island systems. The solution negotiated by DOC and Ngātiwai, whereby kiore are managed under kaitiakitanga on Mauitaha Island and Araara Island but were removed from other islands, could act as a model for place-based co-management in other areas where kiore are considered taonga.
- A full analysis of eradication costs resulting from the inclusion or exclusion of pest species on the list is not attempted here, mainly because:
  - the tools to eradicate most of them are unavailable
  - there is no assessment of eradication feasibility against which we can evaluate cost and risk
  - generalising costs without understanding the context of each eradication is problematic.

  Condensing several operations into one and using eradication and detection techniques that target multiple species have the greatest influence on improved cost efficiencies.
- Two key socio-political risks of targeting any mammalian predator for mainland eradication are public disappointment and despondency if eradications fail, and environmental and animal welfare concerns with the extensive use of toxins. Toxins are likely to be one of the most important tools for eradicating any of the species considered in this report.
- A message that communities often receive is that eradication can be achieved by trapping, but there is no evidence for this, especially for stoats, rodents, and perhaps possums. There are calls to include feral cats on the target list because of their significant impacts on indigenous wildlife, but the socio-political risks of doing so are likely to be higher than for other species, despite an increase in public support for their control on conservation lands.

Recommendations

Given the current knowledge gaps it may be unwise to finalise a species target list until more innovation and development are completed. We therefore make the following recommendations.

1 *Address knowledge gaps that currently limit mainland eradication*

While not excluding possums and ferrets, we recommend that there be a strong focus of research and development on stoats, weasels, Norway rats, ships rats, mice, feral cats, and hedgehogs. Key knowledge gaps and challenges that currently limit eradication prospects include the need to:

a refine and improve the current toolbox, with a particular emphasis on species/genus-specific toxins and, in the longer term, developing novel genetic and other technologies

b optimise species-appropriate deployment strategies, such as effective combinations of tools, tool site placement, density of tools, and timing and duration of deployment

c improve the detection and removal techniques of survivors and re-invaders at very low densities

d understand how animals use landscapes, to inform the optimal distribution and density of devices for detecting and removing residual or invading individuals

e understand the benefits and/or negative consequences of removing, or significantly reducing, the densities of target species, particularly when not all predators are targeted locally

f develop integrated approaches, such as targeting trophic (feeding) relationships to 'supercharge' predator removal by controlling the target species' non-native food supply, both to reduce survival/productivity and to drive increased interactions with traps or toxic baits

g understand the ecological responses of less-studied indigenous biodiversity (bats, frogs, reptiles, and invertebrates) to the removal of predators.

2 *Expand the species target list to include all 10 mammalian predators during the RD&I phase to 2030*

Expanding the current target species list to include mice, feral cats, and hedgehogs is likely to deliver outcomes consistent with New Zealand's biodiversity goals, reduce the risks of perverse ecological outcomes, and open learning opportunities for their eradication. There are strong arguments to include these species based on their demonstrated and potential impacts and the significant biodiversity risks of removing only some members of the predator guild. Also, there is no logical, objective argument – beyond a current capability gap – for excluding some predators, given the goal of protecting indigenous biodiversity and other social, economic, and cultural values.

Giving managers the freedom to target all predator species without risking contractual or funder obligations could lead to greater learning and improved biodiversity outcomes. We recommend that the intent to include all 10 species as targets be signalled as part of the PF2050 strategy review, with the caveat that the programme should focus on fewer landscape sites set within a formalised framework of research and development to fill the current knowledge gaps. No attempt to roll out the PF2050 programme should be undertaken unless the RD&I phase demonstrates that eradication is feasible on mainland New Zealand for one or more species, and that focusing on one subset does not lead to unintended ecological consequences.

There are potential constraints resulting from including feral cats and hedgehogs, in terms of economics (it will cost more), efficiencies (dilution of effort by expanding the scope), system capacity (including insufficient capability), and social licence (some people have an emotional attachment to them, particularly cats). The extra expense of mouse eradication has been assessed and considered to be a modest addition to the fixed expense of targeting rats.

3 Acknowledge the localised taonga status of kiore to some mana whenua

Kiore are a particular case in which management 'at place' on islands must consider and reflect local mana whenua[1] values and perspectives. Although this suggests that arriving at co-management solutions risks becoming overly complex, the very limited distribution of kiore populations nationally means that a rohe-based approach to whether kiore are a target species is feasible for island systems. The solution negotiated by DOC and Ngātiwai, whereby kiore are managed under kaitiakitanga on Mauitaha and Araara Islands but were removed from other islands, could act as a model for place-based co-management in the other few areas where kiore are considered taonga.

[1] Mana whenua: (Māori) territorial rights, power from the land, authority/jurisdiction over land or territory, power associated with possession and occupation of tribal land; the term is sometimes used to describe those associated with such rights/authority, or (more loosely) with tribal links to a specific area.

1 Introduction

Introduced mammalian predators are highlighted as significant biological pressures in Te Mana o Te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020 (DOC 2020). Predator Free 2050 (PF2050) is a national programme to eradicate rats, possums, and mustelids from New Zealand, which sits within a group of national programmes intended to advance the goals of the Strategy. However, PF2050 is currently not ready for roll-out and is focusing in the near term on developing new tools and approaches through research and innovation.

In anticipation of rolling out from 2030, the Department of Conservation (DOC) is carrying out a review of the PF2050 national strategy. A key focus of this review is to consider whether the PF2050 species target list should be changed to ensure wider ecosystem outcomes, by including the full suite of introduced mammalian predators in New Zealand (i.e. adding feral cats, mice, and hedgehogs). DOC commissioned Manaaki Whenua – Landcare Research to produce an insights paper to examine this question. This paper will inform the PF2050 strategy review and will be published alongside the review's discussion document to ensure transparency of considerations.

We begin by reviewing the rationale behind the current target species list, then use scientific evidence and expert opinion to evaluate each species (including feral cats, hedgehogs, and mice) against a standardised set of criteria for inclusion on the list. We identify key knowledge gaps where the focus on research and innovation should be applied, and provide recommendations on the target list in the context of the national PF2050 programme.

1.1 The basis for the current species list

The origins of the target list began with a 'Pest Summit' workshop of researchers and stakeholders convened by DOC in 2012. Possums, stoats, and rats were listed as targets (Tompkins 2018), but apparently 'stoats' was used as shorthand for mustelids, 'rats' as shorthand for rats and mice, and cats were included at the time but later excluded, given lack of social support (B. Beaven, DOC, pers. comm.). 'Possums, stoats, cats, and rats' (with 'rats' becoming a literal interpretation at some point) continued to be the stated list during the establishment of the Predator Free NZ Trust in 2013, after which cats were excluded prior to the New Zealand government announcement of the programme in 2016 and the establishment of PF2050 Ltd in 2017.

An informal email survey conducted in 2014 as part of a New Zealand's Biological Heritage National Science Challenge project asked, 'Which invasive mammal pests would you like to be better able to control, in order of priority?' (Tompkins 2018). Nineteen surveys were returned from central and local government, non-government organisations, consultants, and ecosanctuaries, and rats (species not specified), stoats and possums were chosen as the top three priority species, although ecosanctuaries chose mice over possums as their third priority. The target list was expanded in the Predator Free 2050 strategy (DOC 2020) to include all three rat species and all three mustelid species, with the justification that 'these species (plus possums), collectively, inflict the worst damage of all the introduced predators on New Zealand's wildlife ... we also know more about their biology and control than any other predators.'

This statement implies a two-fold basis for the list – ecological outcomes and feasibility of eradication –, but, as noted by Samaniego et al. (2024), there was no robust evaluation of these criteria, including socio-political, financial, and cultural considerations. Several published criticisms have highlighted concerns about the targeted species, pointing out the inability to achieve broader, ecosystem-level outcomes and the risk of an increase in the abundance of non-target pests (Linklater & Steer 2018; King 2023; Leathwick & Byrom 2023; Samaniego et al. 2024). These issues are discussed in section 5.2.

Although the current list of seven species now seems established, ambiguity continues to this day, with the DOC website giving 'possums, stoats, and rats' as the target list, and referring to them as 'three predators'[2], and the Predator Free NZ Trust website correctly stating 'possums, mustelids, and rats' as the target list, but referring to them as 'five predators'.[3] These ambiguities need to be rectified.

2 Evaluation process for including and excluding species on the list

We review whether the species target list should ultimately change to ensure wider ecosystem outcomes. As suggested by Samaniego et al. (2024), we propose a standardised process to evaluate the outcomes of including or excluding a species on the target list using the following criteria:

- current impacts
- ecological risks
- socio-political risks
- feasibility of eradication.

We used published scientific evidence and expert opinion to evaluate each of the current target species, plus mice, feral cats, and hedgehogs, against these criteria.

3 Predator species reviews

3.1 Brushtail possum (*Trichosurus vulpecula*)

Current impacts. The brushtail possum is a marsupial native to Australia, invasive in New Zealand, and one of the world's worst invasive species (Lowe et al. 2000). In New Zealand, possums are widely distributed across various habitats, including forests, scrublands, grasslands, wetlands, and urban and rural areas, posing a risk to biodiversity, agriculture, and human well-being.

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[2] https://www.doc.govt.nz/nature/pests-and-threats/predator-free-2050/
[3] https://predatorfreenz.org/about-us/predator-free-2050/predator-free-2050-vision/

Possums affect indigenous flora and fauna both directly and indirectly. Their diet includes a wide range of indigenous trees, ferns, other plants, and fungi, as well as vertebrate and invertebrate prey (Green 1984; Nugent et al. 2000; Wood et al. 2015). Possums can change the species composition of forests through browsing (Gormley et al. 2012; Holland et al. 2016; Cowan & Glen 2021). They contribute to the decline of indigenous tree species and can cause local extinction (Campbell 1984; Allen et al. 1997), but their impact may only become noticeable after decades (Campbell 1990). Possums also eat fruit from a wide range of indigenous plant species (Coleman et al. 1985; Cowan 1990), destroying food sources for indigenous fauna, damaging flowers and preventing fruiting (Fitzgerald 1976). Valuable habitat can be further degraded when trees become vulnerable to climate events, parasites, and pathogens as a consequence of significant browsing damage (Clout 2006). Possums can also facilitate the dispersal of invasive species, including plants, fungi, and invertebrates (Rouco & Norbury 2013; Beavon & Kelly 2015; Wotton & McAlpine 2015).

The damage they cause is not restricted to plant life. Possums are omnivores and their diet includes indigenous birds and eggs (Brown et al. 1993). As a result they contribute to the decline of indigenous birds (Clout 2006; Innes et al. 2010) and pose a risk to a wide range of species, such as kōkako (*Callaeas cinera*; Brown et al. 1993), kākā (*Nestor meridionalis*; Powlesland et al. 2009), swamp harriers (*Circus approximans*), kiwi (*Apteryx* spp.), kererū (*Hemiphaga novaeseelandiae*), and muttonbirds (*Puffinus* spp.; Cowan & Glen 2021). They also compete with indigenous species for food and nesting space (Clout 2006).

Possums prey on bats and invertebrates, including snails, wētā (*Hemiandrus* spp.), cicadas, beetles, and stick insects (Cowan & Moeed 1987; O'Donnell et al. 2010; Walker et al. 2024). Management of possums has been shown to benefit indigenous species: their removal can result in the recovery of flora and fauna (Atkinson et al. 1995; Mowbray 2002), including an increase in abundance of birds, invertebrates and frogs (Spurr & Anderson 2004; Byrom et al. 2016; Ruffell & Didham 2017).

Possums cause an estimated annual production loss of $40 million to the primary industry sector through browsing damage and transmission of bovine tuberculosis (bTB), for which they are the primary wildlife vector (Ministry for Primary Industries 2021), with loss estimates increasing up to $100 million, including horticulture (Cowan & Glen 2021). The damage to the health sector has not been quantified, but possums transmit bTB and typhus to humans (Cowan & Glen 2021) and are potential hosts for arboviruses carried by mosquitoes (Derraik 2005).

Ecological risks. Possums compete with ship rats for resources. Eradicating or suppressing possums can cause a significant increase in rat numbers (Sweetapple & Nugent 2007; Ruscoe et al. 2011) and subsequently exacerbate their impacts (see section 5.2).

Socio-political risks. There are few socio-political risks with eradicating possums given they are generally disliked by the New Zealand public. A recent public survey by the Predator Free NZ Trust found that possums are considered the most damaging of the introduced predators (PFNZT 2024). In fact, it may be more socio-politically risky *not* to include them on the target list. This is discussed further in section 5.4.

Possums were, however, introduced to develop a fur trade, and that persists. In 2014 it was estimated the industry generated approximately $130 million for the New Zealand economy and it is believed to be similar today. Currently over 45,000 kg of possum fibre and about 180 tonnes of possum meat are processed. Those involved in these industries, many living in rural communities, will be adversely affected if possum numbers are reduced.

Feasibility of eradication. There are six poisons currently registered in New Zealand for possum control: 1080 (sodium fluoroacetate), cyanide, cholecalciferol (Vitamin D3), phosphorus, pindone, and brodifacoum. Brodifacoum allows for cost-effective multi-species eradications, simultaneously targeting possums, rats, and mice, but its use via aerial application is limited to fenced areas on the New Zealand mainland. As with any eradication, scale is a major challenge, with Rangitoto Island (2,321 ha) being the largest successful eradication to date (Cowan & Glen 2021). Current efforts to eradicate possums from large areas of the New Zealand landscape (south Westland – aerial 1080; Māhia Peninsula – bait stations plus traps) have reduced possum densities significantly, but reliable estimates of residual densities or whether local eradication has been achieved are not yet available.

The toxins available, baiting densities required, efficacy of other tools, plus the slow reproductive cycle and moderate dispersal dynamics of possums mean that the feasibility of eradicating possums from New Zealand can be considered plausible and, as such, less of a priority focus for tool and technique development.

3.2 Ferret (*M. putorius furo*)

Current impacts. Because ferrets rarely climb and are active only at night, their impact is mainly confined to ground-dwelling species, especially those that inhabit burrows at night. These effects, while limited to a smaller suite of indigenous species than those of other mustelids, can still be catastrophic for the affected species. Weka (*Gallirallus australis*) populations are rapidly exterminated when ferrets arrive in an area: they tend to be absent from areas where ferrets are present, presumably because weka populations cannot survive ferret predation (Beauchamp 1997; Beauchamp et al. 2000; King 2017).

Kiwi are also dramatically affected by ferrets (Robertson et al. 2019b), and their distribution is largely limited to areas without ferrets. When ferrets established in Northland they caused a dramatic reduction in brown kiwi (*Apteryx mantelli*) populations and a rapid contraction of their range (Miller & Pierce 1995). Ferrets are known to kill adult kiwi, which can have greater effects on kiwi populations than juvenile predation by stoats (McLennan et al. 1996a; Pierce & Sporle 1997; McLennan et al. 2004).

Ferrets affect the breeding success of all species of penguin that breed on the mainland (Darby & Seddon 1990; Challies 1992; Alterio 1994; Alterio et al. 1998), and burrowing seabirds are also at risk (Hamilton & Moller 1995; Jones 2000; Lyver et al. 2000; Lyver 2000). Ferrets are predators of ground-nesting shorebirds and probably supress or eliminate many species, including black stilts (*Himantopus novaezelandiae*), southern crested grebes (*Podiceps cristatus australis*), and banded dotterels (*Charadrius bicinctus*; (Norbury & Murphy 1996; Rebergen et al. 1998; Keedwell et al. 2002a; Sanders & Maloney

2002; Murphy et al. 2004; Norbury & Heyward 2008; Mills et al. 2018). Ferrets also prey on indigenous lizards and invertebrates, with consumption rates influenced by the abundance of their primary prey – rabbits (*Oryctolagus cuniculus*) (Cliff et al. 2020).

Ferrets pose a threat to New Zealand's agricultural industry because they are potential transmitters of bTB to cattle and deer. Infected ferrets can develop lesions in the respiratory system, with live *M. bovis* (the microorganism responsible for bTB) culture recovered from the oral cavity, indicating a possible route of infection for domestic stock (Ragg et al. 1995; Lugton et al. 1997; Barron et al. 2015; Byrom et al. 2015).

Ecological risks. There are two perceived negative outcomes from ferret eradication: (1) increased rabbit populations, and (2) meso-predator release of stoats. Both outcomes appear unlikely in most habitats. Ferrets have little top-down (controlling) effect on rabbit numbers, which are driven primarily by food availability (Norbury & Jones 2015; Barron et al. 2024). Pierce (1986) suggested that reducing ferret and cat populations might lead to an increase in stoat numbers, potentially increasing predation pressure on wetland birds. There is some evidence of interference competition and spatial segregation between ferrets and stoats, with stoats avoiding areas with high ferret abundance (Ratz 2000; Garvey et al. 2015; Garvey et al. 2022b). This requires further study, but the benefits of ferret eradication probably outweigh any costs of potentially higher stoat numbers. We suggest that the impacts of ferrets on New Zealand's biodiversity are underestimated.

Socio-political risks. There are two social groups that may oppose and hamper efforts to eradicate ferrets: pet ferret owners and farmers. There are many domestic ferret owners in New Zealand, and one Facebook group for ferret owners has over 1,300 members. In some regions ferrets can be owned legally, with certain conditions, while in others they are illegal. Ferret owners who already disregard these laws are unlikely to alter their behaviour regarding keeping and relocating ferrets. The biosecurity risk of this community maintaining small numbers of ferrets in captivity needs to be evaluated. Farmers may also resist ferret eradication attempts given their perception that ferrets control rabbits. There is minimal evidence for this (Norbury & Jones 2015), but the belief that ferrets are useful for rabbit control remains.

Feasibility of eradication. Eradication of ferrets may be possible within a reasonable timeline and with the tool set currently available, providing the risks detailed above can be managed. They are the only target species that has ever been eradicated over a similar-sized area anywhere in the world. Through an intensive campaign of persecution by gamekeepers in the second half of the 19th century, polecats *M. putorius* (the wild ancestral form of ferrets) were eradicated from all of England and Scotland, becoming confined to a small refugium in central Wales (Langley & Yalden 1977; Croose 2016). Since the 1930s their range in the UK has expanded due to decreased trapping effort.

In New Zealand there are unverified claims that ferrets have already been eradicated from Okahukura peninsula (10,700 ha) on the Kaipara Harbour, north of Auckland, using only Havahart collapsible cage traps (M. Pengelly, pest contractor, pers. comm.). In contrast, the largest successful stoat eradication where trapping was the primary tool was Coal Island (1,180 ha). The area polecats were eradicated from in the UK was over 200,000 km^2, which far exceeds the area of each of New Zealand's main islands.

Ferrets also have a somewhat limited distribution in New Zealand: they are scarce west of the main divide in the South Island, and they do not penetrate far into beech forest. Their distribution is patchy in the North Island, and they have been found in some Northland forests, but are absent from northern Northland. In the 1960s ferrets were not present across large areas of the North Island, including Taranaki and Northland (Marshall 1963), only establishing after local releases from ferret farms in the 1980s. In these more recently colonised areas ferrets appear to remain primarily near the release sites, suggesting that their ability to colonise areas and disperse across boundaries or undesirable habitat is limited.

Unlike stoats and weasels, ferrets are relatively easy to isolate with fences. A rabbit fence is likely to contain ferrets most of the time as they prefer not to climb. Rabbit fences can become complete barriers with small modifications to reduce climbing and therefore secure the boundaries of eradication areas.

Significantly suppressing rabbits is likely to increase the effectiveness of ferret suppression and should be considered as a tool to aid ferret eradication, even if complete rabbit eradication is deemed unfeasible (Norbury & McGlinchy 1996; Norbury 2017). Eradicating rabbits as well as ferrets will be more expensive (in the short term) and would inevitably involve toxin use, but it would have significant economic and biodiversity gains in the long term and would reduce the socio-political risks of farmers opposing predator eradication on the grounds of adverse rabbit responses.

Ferrets have a similar home range size to stoats, so a 400 × 400 m trapping grid may be capable of eradicating ferrets if all traps are attractive and active. Ferrets have been eradicated from all fenced sanctuaries via secondary poisoning where aerial anticoagulants have been used to eradicate rodents. Ferret populations are significantly suppressed by aerial 1080 operations through secondary poisoning (Heyward & Norbury 1999; Robertson et al. 2019b).

Ferrets can also be controlled with directly targeted poison in fish paste, with both 1080 and diphacinone shown to be effective (Spurr et al. 2005). Pestoff ferret paste (containing diphacinone) is the only current registered toxin used for ferret control. PAPP (para-aminopropiophenone, or 'PredaSTOP'), a humane, highly toxic poison for carnivores, has also shown promise for ferret control (Fisher & O'Connor 2007; Shapiro et al. 2010; Eason et al. 2014). Eradication using toxins, whether through secondary poisoning or directly targeted poisoning, is likely to be considerably cheaper and with more chance of success than trapping networks.

Considering the likely responses to focused management effort, eradication of ferrets from New Zealand can be considered plausible, and as such less of a priority focus for tool and technique development, although testing of the effectiveness of integrated management, using coordinated rabbit population reductions, would be valuable.

3.3 Stoat (*M. erminea*)

Current impacts. Stoats are a highly invasive predatory species that significantly suppresses a wide range of indigenous fauna. Stoats are the primary predators of 17 of 34 forest birds classified as 'Threatened' or 'At Risk' in New Zealand (Innes et al. 2010). They are particularly harmful to birds that are large, flightless, or have long-dependent young, such as kiwi, kākā, and whio (*Hymenolaimus malacorhynchos*); those in beech forests, such as kākāriki (*Cyanoramphus* spp.), mohua (*Mohoua ochrocephala*), and brown creeper (*Mohoua novaeseelandiae*); and those in alpine environments, such as takahē (*Porphyrio hochstetteri*) and rock wren (*Xenicus gilviventris*) (McLennan et al. 1996a; O'Donnell et al. 1996; Moorhouse et al. 2003; White & King 2006; Whitehead et al. 2008; Weston et al. 2018; Robertson et al. 2019a; King & Veale 2021; Steffens et al. 2022). Stoats also have significant impacts on seabirds, with many vulnerable species extirpated from islands where stoats are present (Miskelly et al. 2017; Miskelly et al. 2021).

Disentangling the effects of stoats and ship rats is challenging, given that both invaded New Zealand at approximately the same time, both are nest predators, and both are nearly ubiquitous across the country. Species that stoats suppress but that are more resilient to the effects of ship rats include kākā, kiwi, takahē, whio, and rock wren. The dramatic increase in kākā on Waiheke Island since the stoat eradication attempt began highlights that stoats are the primary limiting factor for kākā recruitment. Stoats can eliminate many bird species on their own, without the additive effects of other invasive mammals. For instance, South Island saddleback (*Philesturnus carunculatus*) on Maud Island and Orokonui Sanctuary were eliminated by predation from single litters of stoats (Veale et al. 2012). Multiple species of birds, including piopio, rock wren, North Island robin (*Petroica longipes*), mohua, South Island saddleback, and the South Island kokako, went extinct on Secretary Island through stoat predation alone, as rodents and other predators have never established on this island.

Ecological risks. The evidence for increases in rodent populations following stoat control is mixed. Modelling predicts increased rat numbers (Tompkins & Veltman 2006), tempered by food availability (Blackwell et al. 2001). While some field studies confirm these predictions (e.g., Whitau et al. 2023), other studies have not (Ruscoe et al. 2011), concluding that rodents are driven primarily bottom-up by food availability (Choquenot & Ruscoe 2000).

There are unquantified risks resulting from removing only stoats and not ferrets and weasels. Stoats compete with ferrets and temporally and spatially segregate to avoid this conflict (Garvey et al. 2022b). There are historical reports of ferrets in Fiordland in places where there are no ferrets today (Hill & Hill 1987). It seems reasonable to hypothesise that the complete dominance of stoats in some forests (particularly beech) excludes ferrets, therefore ferrets may potentially move into these habitats, with the associated risk of increased kiwi predation. A more likely unwanted outcome of stoat eradication is the ecological 'release' of weasels. Stoats may suppress weasels, and there is some evidence that weasel populations rapidly increase after aerial 1080 baiting due to the lack of top-down control from stoats and the bottom-up effects of increased mice (Murphy et al. 1998).

Socio-political risks. There are no socio-political risks in removing stoats because there is no public support for them. There are, however, socio-political risks in attempting to eradicate them and failing. All the evidence indicates that without predator-proof fences and aerial toxins targeting rodents to achieve secondary poisoning in addition to ground-based measures, stoat eradications will fail. There are currently no tools to eradicate stoats over large landscape scales, but this is not well communicated to the community.

PF2050 is in a research and development phase, and there is no clear solution on the horizon. If the stoat eradication effort on Waiheke Island (9,200 ha) were to stop now, the population would be at carrying capacity within a few years, all biodiversity gains would be lost, and the community support for future conservation work may be in jeopardy. There will also be social licence issues with the use of toxins, which appear to be required for stoat eradication, even on Waiheke Island: 4 years of intense trapping has reduced numbers but has not achieved eradication and may never do so.

Feasibility of eradication. Stoats have been eradicated, at least temporarily, from 15 islands over 100 ha in New Zealand (King & Veale 2021). At almost all these islands, reinvasions from swimming stoats have occurred. This means that no eradication can be seen as permanent until the contiguous mainland is also stoat-free.

PAPP is registered for direct control of stoats. Toxin-based trials showed that stoats are killed by secondary poisoning using brodifacoum (Alterio 1996) or sodium monofluoroacetate (1080)' (Murphy et al. 1999). Stoat eradications in New Zealand have either used aerial application of brodifacoum in a combined rodent and stoat eradication operation, or lured kill-trap networks specifically targeting stoats. New Zealand has the largest stoat eradications ever completed in the world (Coal Island at 1,189 ha is the largest by trapping; Rangitoto and adjoining Motutapu at a combined 3,842 ha is the largest via secondary poisoning). For the island programmes that used anticoagulants as the primary tool, all stoats died from secondary poisoning and these eradications were successful. Also, stoats were successfully eradicated solely through secondary poisoning in all 11 predator-exclusion-fenced sanctuaries where aerial brodifacoum has been used for multi-species eradication operations. While secondary poisoning has always succeeded so far, this method is currently of limited applicability on the mainland due to the challenges of gaining social licence, concerns for human and livestock health, and issues with environmental persistence of brodifacoum (Black et al. 2021; Nguyen et al. 2022).

Stoat eradications using trap networks have so far failed on islands over 1,200 ha, despite intensive campaigns on Secretary, Resolution, and Waiheke Islands. There is ongoing reinvasion on both Secretary and Resolution Islands, but modelling suggests that these stoat populations are primarily maintained through survivors that avoid traps (Veale et al. 2013; Anderson et al. 2016). On Waiheke Island, no immigration has been detected but the stoat population remains, with breeding still occurring 4 years into the eradication campaign. Although Waiheke Island may achieve eradication using a trap network, the effort required, and uncertain results so far suggest that stoat eradication is unlikely to ever be successful on the mainland without significant toxin use.

The fact that stoats can disperse up to 65 km on land and 5 km across water, and that a significant proportion of them, particularly females, avoid traps and detection devices, makes them a very difficult species to eradicate. In Taranaki stoats have dispersed up to 40 km across heavily trapped areas, and on Waiheke Island stoats live within intensive trap grids and move the length of the island successfully breeding. The only successful eradication technique demonstrated for stoats in large areas is aerial toxin using rodents as a secondary poisoning vector. Most areas of the mainland do not have high alpine areas to act as dispersal barriers, so fencing is likely to be required to maintain stoat-free areas.

Without significant technological breakthroughs stoat eradication is considered beyond current capability and should be a high focus for research and development, with emphasis on the development/refinement of effective and targeted toxins, and on detection and removal methods.

3.4 Weasel (*M. nivalis*)

Current impacts. The effects of weasels on indigenous biodiversity are largely unknown. There is nowhere in New Zealand where weasels exist in isolation, and their geographical range is entirely within that of stoats. Weasels eat small mammals, reptiles, birds, and invertebrates in various proportions, but diet tell us nothing about their impact on prey populations. McAulay and Monks (2023) found that weasels have a narrower dietary breadth than stoats, generally preying on items at a higher trophic level, including a greater focus on lizards and small birds in an alpine environment. Lizards were a major component of the diet of weasels in a recent study in Northland (Strang et al. 2018), and rare lizards are eaten by weasels (Miskelly & Conservancy 1997). While there are few studies, it seems likely that weasels have the capacity to significantly affect indigenous reptile populations.

Ecological risks. There are few risks associated with weasel eradication. It is unlikely weasels suppress mouse populations. Weasels can breed up to three times a year and their populations can increase rapidly in response to increasing mouse populations (King & Moors 1979). Weasels were briefly present in Brook Waimarama Sanctuary before being eradicated. Within a year of arriving in the sanctuary their population had reached higher densities than have ever been recorded elsewhere in New Zealand. This is a sobering reminder that a weasel/mouse ecosystem could replace a stoat/rat one, but the consequences of this are unknown.

Socio-political risks. There is minimal foreseeable resistance to the idea of eradicating weasels from New Zealand, apart from the fact that there is no method of suppressing or eradicating them other than using large amounts of anticoagulants.

Feasibility of eradication. Little is known about the suppression or eradication of weasels. In Taranaki the large PF2050 mustelid control programme captures a relatively high number of stoats but only a small proportion of weasels (Veale & Etherington 2022). The sex ratio of weasel captures in this programme is 3:1 male to female, showing that over two-thirds of female weasels are missed by trapping. This is most likely caused by traps being set to trigger with heavier targets and being too widely spaced.

The only weasel eradications in New Zealand have been inside fenced sanctuaries and have involved the complete removal of all mammals through the aerial distribution of anticoagulants. The only eradication effort that specifically targeted weasels was at the Brook Waimarama Sanctuary, where weasels invaded the sanctuary and were eradicated by a baiting operation that targeted mice. This operation was conducted after trapping caught 73 weasels in less than a year without sufficiently suppressing the weasel population (Schadewinkel 2021). Weasel incursions have been detected in other New Zealand fenced sanctuaries, with most having multiple incursions. Each of these incursions was eventually caught or disappeared. Given the close relationship between weasels and mouse populations, eradicating mice may potentially eradicate weasels in some habitats. There are no toxins currently registered for weasel control.

Current knowledge of weasel ecology, behaviour, population monitoring, detectability, and control method efficacy is minimal. Therefore, until there is considerably more knowledge on these topics, or there is social licence for aerial brodifacoum, or support for the eradication of mice, weasel eradication is considered beyond current capability and should be a high focus for research and development.

3.5 Norway rat (brown rat, water rat; *Rattus norvegicus*)

Current impacts. Norway rats are important urban, rural, and commensal pests that threaten stored food, damage cables and buildings, and spread diseases that humans may catch (Wilson et al. 2018b). They are significant threats to nearshore island fauna due to their excellent swimming ability (c. 2 km) and are the rat species most likely to turn up on Mana and Motutapu Islands, near Wellington and Auckland, respectively. On the mainland their patchy distribution implies they are only locally important predators, especially in braided riverbeds (Keedwell et al. 2002b) and on beaches (Dowding & Murphy 2001).

They eat a wide variety of prey, including seeds and fruits, frogs, reptiles, and eggs, chicks and adults of wetland birds and seabirds that live, roost or nest on or near the ground (summarised in Russell & Innes 2021), and even whitebait eggs.[4] Norway rats are a greater threat to adult seabirds than the other rat species because they are larger and can handle larger prey. Norway rats do not climb as well as ship rats, but they can climb, and preyed on kākā and North Island saddleback nests near the ground on Kapiti Island before the rats were eradicated (Moorhouse 1990; Lovegrove 1992). As with kiore, the top-down impact of Norway rats on seabirds has indirect flow-on effects on the food webs and ecosystems of islands (Fukami et al. 2006; Mulder et al. 2009; Towns et al. 2009) and adjacent marine ecosystems (Benkwitt et al. 2021).

Ecological risks. Control of either ship or Norway rats (possibly even kiore) is likely to result in increased mouse numbers and movements due to release from intra-guild predation if mice alone remain (Bridgman et al. 2013). Abundant mice is a frequent outcome in pest-fenced ecosanctuaries when all other introduced mammals are removed (Innes et al. 2024). Following rat eradication, the impacts of mice can increase to the extent that rat removal has no ecological benefit (Samaniego et al. 2024). It is possible that small numbers of mice exist on Stewart Island / Rakiura, for example, but are not detected because they are suppressed by the three rat species. Removing Norway rats alone and

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[4] https://www.nzherald.co.nz/northern-advocate/news/rats-caught-on-camera-eating-shortjaw-kokopu-eggs-in-waipoua-forest/SCPIUKHDGFAGXPK6P4FECCHFIQ/#google_vignette.

leaving other mammalian pests would probably achieve little conservation benefit because of impact overlap between pest species.

Socio-political risks. As with kiore, a 2012 survey revealed that most people thought that rodents should be exterminated in New Zealand (Russell 2014), although it is highly unlikely that many survey participants distinguished between rat species before responding. Domestic strains of Norway rats are used as laboratory and pet (fancy) rats, and there is a 'NZ Rat Club' currently with 1,115 members.[5] It is highly unlikely that eradication of wild Norway rats would have socio-political risks, at least in the short term, although there would be social issues if a yet-to-be-developed biocontrol eradication tool jumped from wild to captive populations.

Feasibility of eradication. Norway rats have been successfully eradicated from very large islands in New Zealand (up to 10,900 ha Campbell Island in 2001; Broome (2009); Russell and Innes (2021) using aerial brodifacoum. Success was largely due to no reinvasion of rats. This approach is not available on the mainland other than in pest-fenced ecosanctuaries due to restrictions on aerial brodifacoum use. Norway rats were probably eradicated from the largest pest-fenced ecosanctuary – Maungatautari (Waikato, 3,290 ha) – but their presence was not verified before eradication (Speedy et al. 2007). Norway and ship rats are typically co-targeted on the mainland because there is generally poor discrimination between the species and because people use the same tools (traps and poisons) for both species. There has been no demonstration of eradication on mainland New Zealand (or the rest of the world) outside pest fences, primarily because of reinvasion.

There are currently no feasible tools to eradicate Norway rats from the New Zealand mainland, given the logistical and operational constraints of existing tools. Therefore, eradication of Norway rats is considered beyond current capability and should be a high focus for research and development, with particular emphasis on the development and/or refinement of rat-specific toxins, and operational best practice for current and emerging tools.

3.6 Ship rat (black rat, roof rat; *R. rattus*)

Current impacts. Like Norway rats, ship rats are important urban, rural, and commensal pests that threaten stored food, damage cables and buildings, and spread diseases that humans may catch (Wilson et al. 2018b). In commensal sites ship rats are often in building ceilings (hence 'roof rat') while Norway rats are dominant on the ground due to their larger size. Ship rats are currently the most common and widespread mainland rat species, occurring in diverse vegetation, especially forests and shrublands, including forest fragments and surrounding pasture (King et al. 2011). They are significant disrupters of ecological systems because they are arboreal and omnivorous, consuming fruits and seeds, invertebrates, reptiles and amphibia, and bird eggs, chicks, and adults (Innes et al. 2010; Innes & Russell 2021). They are a particular threat to nesting passerines in mainland

[5] NZ Ratclub | Facebook

forests because they are superb climbers and can be abundant. They will kill and eat adults up to about their own bodyweight (bellbird size) but can take eggs and chicks of much larger birds, such as kākāpō (*Strigops habroptilus*).

Ecological risks. Mouse numbers can increase due to release from intra-guild predation if ship rats are controlled (Innes et al. 1995; Ruscoe et al. 2011; Goldwater et al. 2012; Bridgman et al. 2013). Mouse detections on camera traps increased steadily in the 4 years following an aerial 1080 operation in the Perth Valley (ZIP, unpublished data), highlighting the potential for perverse outcomes from currently implemented large-scale management regimes. Mice may also become more active following removal of a dominant species (e.g., Bridgman et al. 2018). Stoats have flexible diets and eat more invertebrates and birds when ship rats and mice (preferred prey) are scarce or absent (Murphy & Bradfield 1992; Murphy et al. 1998). Removing ship rats alone and leaving other mammalian pests, including other rodent species, at most sites would probably achieve little conservation value because of impact overlap between pest species.

Socio-political risks. As with kiore and Norway rats, a 2012 survey revealed that most people thought that rodents should be exterminated in New Zealand (Russell 2014). Residents on Great Barrier Island (Aotea Island) argued against eradication of ship rats and kiore (Norway rats are absent) because they worried that mice would increase (Ogden & Gilbert 2009). There may be a risk of public disengagement if publicised eradication attempts against ship and Norway rats fail repeatedly or after long time periods, but there is no sign of this yet.

Feasibility of eradication. Like the other three New Zealand rodent species, ship rats have been eradicated from numerous islands in New Zealand and worldwide, especially after 1990, with targeted use of brodifacoum using GPS and helicopters (e.g. 12,800 ha Macquarie Island, Australia, in 2011; Jones et al. 2016; Innes & Russell 2021). They are also readily eradicated inside pest-fenced ecosanctuaries, such as Maungatautari, with the same (island) tools and techniques (Speedy et al. 2007). Contrary to public opinion, ship rats are not hard to control, but they do persistently reinvade, which has occurred during mainland eradication attempts when fences have not been used (Bell et al. 2019). Zero Invasive Predators are trialling a 'remove and protect' model using mainly repeated aerial 1080 in south Westland but have not yet demonstrated success. Their current strategy involves protecting an approximate 30,000 ha 'core' with a similar-sized surrounding 'buffer' within which re-invaders are targeted.

There are currently no feasible tools to eradicate ship rats from the New Zealand mainland when considering the logistical and operational constraints of existing tools. Therefore, eradication of ship rats from New Zealand is considered beyond current capability and should be a high focus for research and development, with particular emphasis on development and/or refinement of rat-specific toxins and operational best practice for current and emerging tools.

3.7 Kiore (Pacific rat, Polynesian rat; *R. exulans*)

Kiore are one of the seven target species included in the current PF2050 target species list. Given that kiore are culturally significant for some iwi, hapū, and whānau, there needs to be a more nuanced approach to the discussion around, and management of, kiore as we work towards a predator free New Zealand.

Cultural significance of kiore to some iwi, hapū, and whānau. Kiore are widespread throughout the Pacific and Southeast Asia, and were introduced to New Zealand by Māori settlers around the 13th century (Roberts 1993). They are significant to many tangata whenua, particularly Ngātiwai, because they have a shared history of migration to New Zealand, are closely associated with the kūmara, and are part of Māori cosmology, featuring in legends, whakapapa, and astronomy (Haami 2008). This is reflected in Ngātiwai kōrero, which note the kiore are

> *old and respected shipmates, who have occupied this island for as long as we have. We have co-habited with them throughout our voyaging in the Pacific and in our entire residency in Aotearoa. They have continued to sustain our tupuna... We consider we have a responsibility toward their survival and well-being as part of our ancestral kaitiaki responsibilities.* (Kapa 2003)

Further oral and written evidence demonstrates the many different relationships between tangata whenua and kiore across the country. Some consider kiore a part of their whakapapa and/or traditional practices (Haami 1993). Tūhoe, like many iwi, see kiore as a delicacy to be fed to esteemed guests during ceremonial occasions (Haami 1993). There are records of kiore being fed to guests as recently as 1916, during the arrests of Rua Kenana. Kiore were one of many foods that Māori selected according to seasonal variation in quality and abundance, and their condition also indicated the availability or ripeness of other foods sought by both kiore and humans (Haami 1994; Williams 2010).

Kiore are also embodied in toi Māori (Māori art); for example, kiri-kiore is a carving pattern that refers to the skin of the kiore (Haami 2012), and wharenui (meeting house) carvings, typically in northern tribal lands, depicting kiore symbolise their coexistence with humans. One example is the carved window frame of Te Ōhākī wharenui at Roma marae in Ahipara, which depicts the story of a tupuna (ancestor), Ruanui, who released a kiore onto Motukiore (Rat Island, Haami 2008). Other practices include matakiore, a form of tā moko (tattoo) that transfers mātauranga (knowledge) from fathers to daughters, usually related to environmental and/or kiore management.

Ngātiwai are the only group recorded as having secured specific legal protection for the management of this species. For Ngātiwai, kiore are a taonga species of cultural significance and a key part of the ecosystem within their tribal rohe (Kapa 2003). Ngātiwai narratives capture the history of their association with kiore and the traditions that have emerged from that relationship, particularly in relation to the use of kiore pelts in traditional ceremonies (Kapa 2003).

This special relationship was formally acknowledged in the 2010 Memorandum of Agreement between the Minister of Conservation and the Ngātiwai Trust Board (DOC 2010a; Wehi et al. 2021). The management agreement enables Ngātiwai to enact kaitiakitanga (guardianship) on two small offshore islands, Mauitaha and Araara in the Hen and Chicken Islands Nature Reserve, despite populations of the species being removed from other islands in the group (DOC 2010b). Kaitiakitanga encompasses management of population numbers through the cultural harvest of kiore, and the use of the animals themselves as a tohu (traditional indicator of ecosystem state); for example, of tawāpou (*Planchonella costata*) fruit abundance (Haami 1994; Wehi et al. 2021).

Ngātiwai's expression of kiore as a taonga (treasure) also underpins the ethos of Wai 262, because it demonstrates the kaitiaki relationship between the tribe and kiore, and the mātauranga associated with them. While Ngātiwai are the only tribal group who have their relationship with kiore recognised in a legal agreement, it is important to note that kiore are subject to Wai 262 provisions across the country. The Wai 262 claim addresses the rights of Māori over indigenous flora and fauna (including kiore), as well as their cultural and intellectual property rights related to these taonga (WT 2011).

Environmental Court Commissioner, Waitangi Tribunal Member, and Conservationist of the Decade Kevin Prime CNZM (Ngāti Hine) has stated that

> *If 'kiore' is referring to our native rat then it would definitely be classed as one of our taonga species and should not be included amongst the target species. My parents and grandparents did not eat kiore but my great grandparents (1840–1920) did, but preferred beef, pork and mutton. They felt aroha for these mokai (pets) as they left kūmara outside of the Pataka to ensure they did not starve.*

Ngātiwai tohunga and rangatira Hori Parata expressed the distinction between kiore, a taonga, and introduced rats as 'Calling a kiore a rat is like calling a Māori a Pākehā'.

Current impacts. Impacts of kiore on the mainland are presumably comparatively minor now due to their very localised distribution in parts of Fiordland and the fact that ship rats and mice are also present at those sites. However, on islands their impacts are significant, and they may be abundant if they are the only species present or if coexisting ship or Norway rat numbers are reduced. Kiore are a small rat, so they affect small prey such as invertebrates, lizards, and seeds, but they also prey on juveniles and eggs of tuatara, and on bird eggs and chicks, including Pycroft's petrel (*Pterodroma pycrofti*), little shearwater (*Puffinus assimilis haurakiensis*), Cook's petrel, North Island saddleback, and kākāpō (Wilmshurst & Ruscoe 2021).

Impacts can be significant: predation by kiore was the probable cause of failure for at least 75% of little shearwater nests on Lady Alice Island (Booth et al. 1996); tuatara, particularly immature animals, were scarce or absent on islands with kiore compared to those without (Crook 1973); and recruitment of a range of coastal indigenous trees was reduced due to kiore consumption of seeds, flowers, and seedlings (Campbell & Atkinson 2002).

Following the removal of kiore from islands there have been marked increases in indigenous geckos (Hoare et al. 2007), tuatara (Towns et al. 2007), burrow-nesting seabirds (Pierce 2002), wētāpunga (*Deinacrida heteracantha*) (Green et al. 2011), and seedling recruitment (Campbell 2011). As with the other, larger *Rattus* species, kiore invasion on islands results in fewer burrow-nesting birds and consequently less soil turnover and guano accumulation. This changes the soil and leaf chemistry and leaf production, with cascading effects on soil invertebrates (Fukami et al. 2006; Mulder et al. 2009; Thoresen et al. 2017).

Ecological risks. Like mice, kiore may be scarce and inconspicuous if either ship or Norway rats are present, and then become abundant or at least detectable when these larger rats are controlled (Russell & Clout 2004; Russell & Innes 2021). A kiore removal experiment on Raoul Island from 1994 to 1996 showed that kiore were trappable only after Norway rat numbers were reduced by half, suggesting intense interference competition or intra-guild predation (Harper & Veitch 2006).

Socio-political risks. A 2012 survey revealed that most people thought that rodents should be exterminated in New Zealand (Russell 2014). However, it is likely that respondents were not thinking much about the differences between rat species. The importance of kiore as cultural taonga for some mana whenua is discussed above.

Cultural considerations of inclusion of kiore as a PF2050 target species. Kiore provide an example of the need to undertake a nuanced approach to the management of taonga species. While a patchwork approach to managing kiore on the mainland is likely to be problematic, it is feasible to maintain populations on remote islands where the species have significant cultural value (e.g. Mauitaha and Araara islands within Ngātiwai's tribal boundary). Jane Kitson (Ngāi Tahu ki Murihiku-Ōraka-Aparima, Waihopai and Awarua Rūnanga) has been undertaking recent interviews with whānau and communities across Murihiku in the context of understanding the way people value different species through the 'Fish Futures' programme. Kitson notes the diversity that exists between Murihiku whānau in relation to the pest status of kiore, and specifically in relation to the inclusion of kiore in Predator Free Rakiura. The view that kiore should be given pest status is recorded in the Ōraka Aparima Rūnaka Inc. Annual Report (July 2017-June 2018) (OARI 2018), where Tane Davis said,

> *Twenty years has passed since Whenua Hou was successfully eradicated of kiore. The island has certainly bounced back to its natural state without the presence of kiore and in turn, this has enabled a series of endangered taonga species to be transferred to the motu. The threat to the kākāpō no longer exists without the presence of kiore.*

In recent conversations with Murihiku whānau, some interviewees stated kiore do not belong as priority species within Predator Free Rakiura; others say they do, or perhaps need a place to belong as they have strong connections to Māori. The results have not yet been analysed, and Kitson expects that there may be more to add to the discussion in a year or two. There have been associated concerns that eradication of kiore from Stewart Island / Rakiura would represent the loss of a locally distinct taonga compared to the wider New Zealand population of the species. Genetic evidence suggests that this is not the case, and that Stewart Island / Rakiura kiore are similar to kiore found in the rest of the country, with the greatest similarity to those on Kapiti Island, which is the southern-most other population sampled (Matisoo-Smith et al. 1999).

Ngāi Tahu environmentalist and oral historian Tūmai Cassidy has noted that prior to colonial settlement, kiore and birds existed alongside each other in a state where both were in 'abundance'. It is unlikely that we will be able to get back to that perceived state of mutual abundance and balance, although the perception may also reflect the fact that, because of their relatively small size, kiore may have less impact on some, larger, bird species than on others (summarised in Jones et al. 2015). Kiore's status as valued mahinga kai may also have been diminished due to the perception that parasites that came to New Zealand with Norway and ship rats may make it hard, or simply less appealing, for Māori to harvest kiore in the future.

Pest management, whether at a national scale or at place, is heavily dependent on social licence to operate, of which cultural licence is a significant component in New Zealand. Kiore are a case whereby management at place must consider and reflect local mana whenua values and perspectives. The brief discussion above illustrates that these values and perspectives may vary, even within rohe. Although this suggests that arriving at co-management solutions risks being overly complex, the limited distribution of kiore populations nationally means that a rohe-based approach to whether kiore are a target species is feasible for island systems. The solution negotiated by DOC and Ngātiwai, whereby kiore are managed under kaitiakitanga on Mauitaha and Araara but were removed from other islands, could act as a model for place-based co-management in other areas where kiore are considered taonga.

Feasibility of eradication. Kiore are now readily eradicated from larger islands using ground and aerially dispersed brodifacoum baits. They have been eradicated from 37 islands larger than 5 ha, including Raoul (2,965 ha, in 2002) and Hauturu (3,079 ha, in 2004) islands, and from 20 smaller islands (Wilmshurst & Ruscoe 2021). Kiore were eradicated from Rangitoto and Motutapu Islands (3,842 ha) during 2009−2011 in an operation that also removed stoats, cats, hedgehogs, rabbits, mice, Norway rats, and ship rats (Griffiths et al. 2015). On Great Barrier Island / Aotea Island, kiore are targeted by trapping and poisoning. Eradication of kiore on the mainland has not yet been attempted. Because of their restricted distribution on the mainland, it may be possible to eradicate kiore with aerial 1080 (notwithstanding its use as a suppression tool only) or brodifacoum (if permitted), although their distribution may be far greater than is currently known.

Kiore eradication in New Zealand is complex, although they are likely to be susceptible to other rat eradication methods. The primary consideration beyond the technical needs already identified above for other rat species is socio-cultural.

3.8 House mouse (*Mus musculus*)

Current impacts. House mice are the most widely distributed small mammal in the world (Singleton & Krebs 2007) and pose a risk to biodiversity, agriculture, and human well-being. The house mouse is one of the 14 mammals included in the list of the world's worst invasive species (Lowe et al. 2000).

The negative impacts of mice on biodiversity are well documented. Mice are omnivores but often show a preference for a more carnivorous diet (Jones et al. 2003; Shiels & Pitt 2014). They can have large impacts on invertebrates and related ecosystem functions (St Clair 2011). Mice also prey on larger species, including big seabirds (Caravaggi et al. 2019; Duhr et al. 2019; Connan et al. 2024), song birds (Michelsen-Heath & Gaze 2007), and large lizards (Norbury et al. 2014). In New Zealand the negative effect of mice has been shown for various invertebrates, including wētā, beetles, spiders and earthworms, reptiles, birds including rock wren (*Xenicus gilviventris*), and plants (see Murphy & Nathan 2021). Mice can also negatively affect tree recruitment through seed predation (Ryan et al. 1989).

Mice have a negative effect on human well-being by being perceived as a nuisance and inducing stress and fear (Randler et al. 2012). They consume food inside houses and contaminate areas with urine and faeces. They also cause structural damage by chewing through walls, furniture, wooden beams, and electrical wiring. Historically, rodents have played a major role in the transmission of disease, and still function as a reservoir for human zoonoses, including leptospirosis, hantavirus, toxoplasmosis, salmonellosis, and campylobacteriosis (Singleton et al. 2003; Charrel & de Lamballerie 2010; Williams et al. 2018; Moinet et al. 2024). Mice can also have a negative economic impact on agriculture (e.g., Brown & Henry 2022).

Ecological risks. There appear to be few ecological risks of eradicating mice, apart from possible short-term prey-switching to indigenous fauna by top-order predators that primarily consume mice (Smith & Jamieson 2003).

Socio-political risks. There are few socio-political risks given that mice are mostly disliked by the New Zealand public. However, there are future socio-political risks concerning the potential widespread use of toxins and genetic tools. These are discussed in section 5.3.

Feasibility of eradication. Currently, the most effective tool for eradicating mice is brodifacoum, which is also widely used for rat eradications. The sole eradication attempt using aerial 1080 (Varanus Island, Australia, 1993) was unsuccessful, and although this toxin has reduced mouse populations to very low numbers in some places, it is considered only variably effective against mice, so that currently there is no effective large-scale mouse control tool for mainland sites (Innes et al. 2024).

Mice have already been removed from 28 New Zealand islands (Broome et al. 2019), and the success rate of mouse eradication from islands is now higher than that of rats (Samaniego et al. 2021). In eradication operations where rats are targeted it is advisable to target mice at the same time for economic, technical, social and environmental reasons (Samaniego et al. 2024). Due to interference with detection devices, not including mice in such operations makes declaring successful rat removal and biosecurity costly and nearly impossible.

Targeting mice in separate operations in the future would increase operational costs significantly, require a new social licence, potentially increase environmental toxic load, and be a loss of investment in infrastructure and expertise (Samaniego et al. 2024). Furthermore, biodiversity outcomes after rat eradication may not be achieved until mice are also removed (Duhr et al. 2019). Currently the biggest limitation to mouse eradications in human-inhabited areas is logistics. Ground-based operations using traps and bait stations are expensive and require access to every building to deploy them inside, which requires the full support of all property owners (Harper et al. 2020).

Eradication of mice from New Zealand is considered beyond current capability and should be a high focus for research and development, particularly if they are included in the list of target species after this review.

3.9 Feral cat (*Felis catus*)

Current impacts. Feral cats prey on a wide range of vertebrate and invertebrate species in New Zealand and have contributed to declines or local extinctions of many indigenous species. Examples include shorebirds (Dowding & Murphy 2001), ground-nesting birds on braided riverbeds (Sanders & Maloney 2002; Cruz et al. 2013b), wetland birds (O'Donnell et al. 2015), forest birds (Veitch 2001), kiwi (McLennan et al. 1996b), bats (Molloy 1995; O'Donnell 2000), lizards (Norbury 2001; Tocher 2006), and tuatara (*Sphenodon punctatus*; (Veitch 2001).

The impacts of cats can be difficult to disentangle from those of other introduced predators, but where these other species are uncommon, such as on some offshore islands, cat impacts are especially clear (Gillies & van Heezik 2021). Most studies have focused on feral cats, although companion cats are likely to have similar impacts (van Heezik et al. 2010). Individual cats differ in their predatory behaviours; for example, focusing on different species or size categories of prey. These differences may be related to the physical and/or behavioural traits of the individual cat (Garvey et al. 2020). Where cats have been eradicated from fenced sanctuaries or offshore islands, substantial recovery of indigenous species has occurred (Campbell et al. 2011; Fitzgerald et al. 2019).

Cats in New Zealand can carry a range of infectious diseases, some of which can affect humans or other animals (Thompson 2009; Glen et al. 2023). For example, cats are necessary hosts for the life cycle of the protozoan parasite *Toxoplasma gondii*, which causes toxoplasmosis. Toxoplasmosis can be dangerous to humans, especially pregnant women and people who are immunocompromised (Montoya & Remington 2008; de Wit et al. 2019). Toxoplasmosis has been recorded in indigenous wildlife in New Zealand and has often been fatal. Recorded cases include several species of conservation concern, such as kiwi, kākā, red-crowned kākāriki (*Cyanoramphus novaezelandiae*), and Hector's and Māui dolphins (*Cephalorhynchus hectori* ssp.) (Roe et al. 2013; Roberts et al. 2021). Toxoplasmosis is also of concern to the livestock farming sector because it can cause abortions in sheep and deer (Dubey 2009; Patel et al. 2019).

There are no current estimates for the damage costs of cats in New Zealand. Globally, feral cats are estimated to cause economic damage of US$43 billion (in 2017 value; (Cuthbert et al. 2022). However, this estimate does not include the intrinsic value associated with biodiversity. For example, damage to wild bird populations by feral cats in the USA based on the amount bird-watchers, hunters, and bird rescuers spend on birds was estimated at US$17 billion per year (Pimentel et al. 2005).

Ecological risks. There is evidence of competition among cats, ferrets, and stoats, suggesting that control of larger predators may lead to changes in the abundance and/or activity patterns of smaller predators (Garvey et al. 2022a). Eradication of cats on Te Hauturu-o-Toi / Little Barrier Island initially led to meso-predator release of kiore, which reduced the breeding success of Cook's petrels (*Pterodroma cookii*). This effect was reversed following eradication of kiore (Rayner et al. 2007). Cat eradication could theoretically cause ecological release of other rodent and mustelid meso-predators; however, this risk can be mitigated through multi-species predator control. Although some land managers express concern that cat control could lead to increases in rabbits, empirical evidence does not support these concerns (Norbury & Jones 2015; Barron et al. 2024).

Socio-political risks. Cats are highly valued as companion animals in New Zealand (NZCAC 2017). Eradication of feral cats may therefore meet some resistance from sectors of the population, and any move to include cats as a PF2050 target species will need to make clear that the focus is on feral cats only, and will thus require the acceptance of registration and regulation regarding the ownership of fertile cats and their breeding. There is increasing awareness in the New Zealand public of the impacts of feral cats on biodiversity and other values. The recent Predator Free Trust survey showed that over half of those surveyed considered feral cats a significant problem for indigenous species, and 60% supported feral cat control on conservation land (PFNZT 2024).

Feasibility of eradication. Aerial distribution of toxic baits is the most cost-effective method for reducing feral cat populations, especially over large areas (Campbell et al. 2011; Fisher et al. 2015). However, this method is not suitable for areas with human habitation. Globally, the largest island from which feral cats have been eradicated is Dirk Hartog Island, Western Australia (62,700 ha). In New Zealand, the largest is Te Hauturu-o-Toi / Little Barrier Island (3,200 ha) (DIISE 2018). Cats have also been eradicated from fenced sanctuaries up to 3,800 ha on the mainland (Innes et al. 2019).

DOC is evaluating the feasibility of cat eradication on Stewart Island / Rakiura (174,600 ha), but this would require the development of new tools, including baits for aerial and ground deployment (Glen et al. 2022). The feasibility study for eradication of cats on Auckland Island is complete and is a useful example for the Predator Free initiative. This includes the current trials of aerial 1080 meat baits. PAPP and 0.1% 1080 feral cat bait are the only toxins registered for cat control.

The logistical challenges of accommodating the safety of domestic cats and dogs means that even with new toxins or baits, eradication of feral cats from New Zealand is considered beyond current capability and should be a high focus for research and development, with an initial focus on refining and developing tools and tactics for public conservation land and rural environments.

3.10 European hedgehog (*Erinaceus europaeus occidentalis*)

Current impacts. Hedgehogs are primarily insectivores and are a potentially serious threat to indigenous invertebrates with terrestrial life-history stages, including threatened or endangered species and particularly those with clumped or restricted distributions (Dowding 1993; Hamilton 1999; Sanders & Maloney 2002). Similarly, small lizards are likely to be particularly vulnerable because they become less active as temperatures cool overnight and when hedgehogs are foraging. Individual hedgehog droppings collected near Alexandra contained up to 10 feet of McCann's skink *Oligosoma maccanni*, and up to two indigenous gecko feet (Jones & Norbury 2011). Remains of indigenous skinks were found in 21% of hedgehog guts from Macraes Flat in Otago (Spitzen-van der Sluijs et al. 2009). Skinks are three to four times more likely to be eaten by female hedgehogs, especially during the peak energetic demands of breeding (Jones et al. 2005; Spitzen-van der Sluijs et al. 2009).

Hedgehog predation on the eggs of New Zealand ground-nesting birds is common at some sites. For example, in the Mackenzie Basin between 1994 and 1999, hedgehogs were responsible for 19% of all recorded lethal events at 172 monitored banded dotterel, black stilt, and black-fronted tern nests on braided riverbeds (Sanders & Maloney 2002). In the 2000/01 season this figure rose to 78% (Sanders & Brown 2001). Video surveillance in 2006 of 198 nests of banded dotterels, nationally vulnerable wrybills, and declining South Island pied oystercatchers across four Mackenzie Basin riverbed sites revealed nest predation rates by hedgehogs as high as 51% (G. Norbury, unpublished data). Hedgehogs were responsible for two of every three losses of New Zealand dotterel nests in sand dune habitat at Tāwharanui (Dowding 1998).

Diet studies of hedgehogs provide circumstantial evidence of potential impacts on indigenous biodiversity, but few studies have attempted to quantify this impact in terms of the abundance or population viability of indigenous species populations. Innes et al. (2010) estimated that hedgehogs were responsible for almost 90% of the 740 g/ha of invertebrate biomass eaten nightly by introduced mammals in North Island podocarp-broadleaf forest, and Jones et al. (2013) demonstrated negative relationships between hedgehog density and the abundance of both juvenile McCann's skinks and ground wētā.

Ecological risks. There are likely to be few ecological risks resulting from removing hedgehogs from an ecosystem. Hedgehogs are not direct predators of other introduced mammalian pest species, and the likelihood of releasing introduced invertebrates from predation following hedgehog eradication is extremely low. The extent to which eradicating hedgehogs would allow competitive release of other small mammals, such as rodents, that feed on invertebrates is unknown.

Socio-political risks. Hedgehogs are considered relatively benign by large sections of the New Zealand public, many of whom view them positively because of their anthropomorphic portrayal in European children's literature and other media, and because of a perception that they control garden pests, for which there is no evidence. Although they are not as important to people as domestic cats, care should still be taken in explaining why hedgehogs are targeted for eradication to obtain the necessary social licence.

Feasibility of eradication. Despite the inclusion of hedgehogs as target species in many trapping programmes designed to protect indigenous fauna, the level of hedgehog control needed to gain any benefit has not been established. They are readily trapped by a range of standard small mammal kill-traps and often dominate the captures. Despite this apparent high trappability, some individuals may avoid traps altogether (C. Jones unpubl., Goodman 2024). DOC 150, 200, and 250 traps have met the National Animal Welfare Advisory Committee criteria for kill-traps targeting hedgehogs (unpublished data cited in Warburton et al. 2008; DOC 2019), although the aperture sizes of DOC 150 and 200 trap sets may be too small to allow access by the largest individuals (Jones et al. 2021).

An ongoing hedgehog removal programme on 3,000 ha of Kaitorete Spit in Canterbury uses a 'rolling front' of double-door cage traps moved through the landscape in a systematic fashion within a tight trapping grid, followed by a network of DOC 150/DOC 200 kill traps and detection sweeps with highly trained dogs and cameras. This has removed hedgehogs to the point where dog searches are unable to detect any survivors

(T. Sjoberg, Predator Free Banks Peninsula, pers. comm.), a result undoubtedly aided by little or no reinvasion onto the spit.

Hedgehogs were part of the suite of introduced mammal pests eradicated from the islands of Rangitoto and Motutapu in the Hauraki Gulf, and on Ōtamahua / Quail Island near Christchurch (Kavermann et al. 2003; Griffiths et al. 2015). In both cases, multiple eradication methods were used, making it difficult to examine the relative effectiveness of each method. On Ōtamahua / Quail Island, removals were initially by live trapping, followed by kill-trapping (using Fenn traps) and spotlight searches. Again, these achievements would have been aided by zero reinvasion.

Hedgehogs are susceptible to brodifacoum poisoning (Alterio 1996), but its effectiveness as a control tool is likely to depend on several factors. For example, intensive control, such as that carried out at Karori/Zealandia and on Rangitoto−Motutapu (Griffiths et al. 2015) seems to have been effective but, in other circumstances hedgehogs appear to have a level of tolerance to brodifacoum, possibly when it is encountered over prolonged periods. The degree to which secondary intake, particularly via scavenging, contributes to reported toxin loads in hedgehogs is also unknown, although data from the Rangitoto−Motutapu eradication suggest that primary bait ingestion occurs. Given these uncertainties, coupled with the long time to death and poor welfare outcomes, and restrictions on widespread use, this toxin is a less preferred option for hedgehog control at landscape scales.

Like other small mammals, hedgehogs are susceptible to 1080 and are often noted as by-kill in operations using the toxin. It is not known whether the marked decline in hedgehog activity following an aerial 1080 operation (Dilks et al. 2020) was the result of primary poisoning through direct bait consumption or secondarily through scavenging of the many carcasses that are likely to have been present in the treated area. In a pen trial, 1080-laced feral cat baits (0.1% 1080 in a fish meal-based pellet) killed hedgehogs that ate them; however, bait acceptance and palatability were comparatively low (Brown & Jones 2022). In the same study, alphachloralose bird paste had reasonable efficacy and was also a relatively humane and fast-acting toxin when consumed in sufficient quantities. Further trials on bait delivery matrices are underway to support the relabelling of alphachloralose for use against hedgehogs.

Existing tool limitations and the logistical constraints of broad-scale use of aerial toxins mean that eradication of hedgehogs from New Zealand is considered beyond current capability and should be a strong focus for research and development.

4 Summary of each criterion

4.1 Current impacts

Numerous New Zealand studies have documented the impacts of the above pest species on a wide range of indigenous fauna and flora. Depending on the location, all 10 species considered here affect one or more of their major food groups (plant foliage, seedlings, seeds, bats, forest birds, ground-dwelling birds, eggs, reptiles, frogs, and invertebrates).

To identify which pest species should ultimately be included on the PF2050 target list we would ideally rank them according to their degree of impact, but there is no objective way of doing this. Most impact studies measure responses to multi-species pest control (e.g., Innes et al. 2010; Watts et al. 2011; Reardon et al. 2012; Elliott & Kemp 2016), making it difficult to attribute impacts on biodiversity to a single predator species. Pest species are rarely present on their own, and their interactions can synergise their effects, so they must be evaluated together.

For mustelids, the effects of stoats are by far the best understood. This is partly because they are regularly found on islands without ferrets and weasels, and sometimes without any other introduced small mammals. Some studies measure pest-specific rates of predation on birds (e.g., Sanders & Maloney 2002; Innes et al. 2015; Bell et al. 2021), but they are uncommon, and in the case of rats, pest species cannot always be distinguished. Also, there is huge spatial and site-specific variation in abundance and species richness of both pests and indigenous biota (Innes et al. 2010), and variation in factors that influence predator impacts, such as habitat quality (Norbury & Reardon 2023). In fact, some indigenous species do not respond at all to predator control at some locations; for example, black stilts (Keedwell et al. 2002a) and lizards (Monks et al. 2024).

An alternative way to rank pest species by impact is to use the number of impact studies published in the scientific literature for a given pest species, but this assumes no publication bias, which is undoubtedly false. The bulk of New Zealand published studies focus on the impacts of possums, stoats, and ship rats on mainland forest birds (Innes et al. 2010). There are far fewer impact studies on weasels, Norway rats, kiore, and hedgehogs, and relatively few studies on bat, frog, reptile, and invertebrate responses to predator removal. As a result it is very difficult to rank pest species by impact.

While not overcoming these problems entirely, it may be more valid to rank pest species by *groups* according to their *collective impact*. In this case, notwithstanding potential publication bias, the possum/stoat/ship rat group could arguably be ranked first, at least in terms of their effects on forest birds (Innes et al. 2010). Indeed, the acute nature of these impacts, coinciding with episodic beech masting events, has been the basis of the multi-million dollar National Predator Control Programme to protect iconic forest birds (Elliott & Kemp 2016). Ship rats, in particular, are one of the more ubiquitous pest species across New Zealand, and have been implicated in many extinctions, declines, and range contractions of indigenous birds (Whitau et al. 2023).

But even the approach of prioritising introduced predator species for inclusion in PF2050 carries some uncertainty. While less studied predator species, such as mice and hedgehogs, may have smaller individual impacts on more noticeable indigenous species, at a population level they may still cause significant aggregated impacts on key ecosystem processes due to their high abundance and predatory focus on smaller prey items such as seeds, invertebrates, and lizards.

4.2 Ecological risks

One of Leathwick and Byrom’s (2023) criticisms of the PF2050 programme is that the current list of target species ‘over-simplifies the challenges of managing the complex, interacting assemblages of species'. Numerous overseas and New Zealand studies show that selective removal of pest species can lead to increases in other pest species through release of predation or competition ('meso-predator release'), sometimes leading to so-called 'perverse' outcomes. In New Zealand, the evidence points mainly to ship rat increases following possum, mustelid or cat control, or mouse increases following ship rat, mustelid or cat control, but this depends on food availability (Tompkins & Veltman 2006; Sweetapple & Nugent 2007; Ruscoe et al. 2011; Goldwater et al. 2012; Norbury et al. 2013; Wilson et al. 2018a; Whitau et al. 2023).

The difficulty lies in understanding the *net outcomes* for indigenous species. For example, what is the net outcome when ship rats are removed and mice increase? Research would suggest overall benefits for forest birds (which are hunted mainly by rats, not mice), but overall detriments for small prey species, such as invertebrates and small lizards, which are more accessible to mice. Studies of net outcomes are uncommon, making it difficult to assign ecological risk to the removal of a given pest species or subset of species. Clearly, removing all invasive pests is the best way to extinguish ecological risk and maximise benefits (Glen et al. 2013; Horn et al. 2019), but a better understanding of the ecosystem impacts of removing some species but not others is a key knowledge gap when designing overall strategic approaches with a view to protecting biodiversity values.

4.3 Socio-political risks of *inclusion* on the target list

Including species on the target list without acknowledging the low prospects of eradication with current approaches risks public disappointment, despondency, and disengagement. Failures may lead to a lack of support and social licence for pest management in general.

Communities are keen to eradicate pests, but they may not want to use toxins. Some of the messages communities receive create the impression that eradication can be achieved by trapping, but there is no evidence for this, especially for stoats, rodents and, probably, possums. Toxins are likely to be one of the most important tools for eradicating any of the species considered here. Given the growing public opposition to their use (Russell 2014), the more pest species on the target list, the greater the likelihood of public backlash to toxin use.

New Zealand's international agricultural markets are potentially at risk with the extensive use of toxins and perceived inhumane treatment of animals (Linklater & Steer 2018). Gene technology is considered by some to be a necessary tool for eradication at national scale, but it has yet to be developed for mammalian species and is highly controversial because of its potential for unintended, uncontrollable consequences (Esvelt & Gemmell 2017). Given it is still unproven for any mammal, although it is important to investigate, it cannot be relied upon as a solution and is unlikely to ever be so for any species larger than rats due to the relatively slow generation times. More targeted toxins that are currently under development are (optimistically) years away from being commercially available.

Many landholders across New Zealand are concerned that removal of mustelids and feral cats will lead to increases in rabbit numbers (McKelvie-Sebileau 2020). People apply the intuitive logic that if predators consume rabbits, they must regulate their numbers.

However, predator–prey population dynamics are rarely that simple. The evidence suggests that rabbit numbers are controlled mainly by climate, food, and disease with relatively little effect of predators (Norbury & Jones 2015; Barron et al. 2024). In fact, rabbits drive predator abundance rather than the other way around (Cruz et al. 2013a).

Nevertheless, public perceptions are critical, and much is at stake in terms of relationships between government, non-government organisations, and landholders. Some landholders are requesting compensation for rabbit control because of predator removal in their local area. Therefore, without rabbit eradication the motivation for illegal releases of predators would persist.

Whether due to concerns about toxin use or rabbit increases, some landholders may refuse access to their properties, which could violate the first rule of pest eradication that all individuals be at risk of removal. While this can be circumvented to some extent by deploying devices on property boundaries, it can be problematic if the properties are very large and the predator home ranges are small.

There are calls to include feral cats on the target list (e.g., Rouco et al. 2017), but the socio-political risks of doing so must be acknowledged. New Zealand has the highest rate of cat ownership in the world (Glen et al. 2023) and is relatively free of restrictive legislation. Widespread killing of cats will be highly contentious given the strong cat welfare lobby, although a majority of the public appear to support control of feral cats to protect biodiversity (PFNZT 2024). Mainland eradication of feral cats must consider the effects of consistent immigration/dispersal (natural or human-facilitated) from the domestic and stray populations. While neutering programmes and containment of domestic cats will help, they do not address the stray population (which some people nurture and feed). Urban and rural cats will therefore continue to be a source of reinvasion into the wild population unless a solution is found.

Hedgehog eradication, due to the species' Eurocentric media portrayal, may also represent a social licence risk, but probably to a lesser degree than cats. Again though, the recent Predator Free Trust survey placed them among the most damaging predators to New Zealand's indigenous species (PFNZT 2024).

4.4 Socio-political risks of ***exclusion*** from the list

Excluding possums from the list may have implications for the bTB eradication programme and may create discontent and frustration in the rural sector. Urban and rural possums damage gardens and are a general nuisance. People generally dislike possums, so there is likely to be widespread disappointment if they are excluded from the list. The socio-political risks of excluding other species on the list are relatively minor, although ship rats and Norway rats pose concerns for human health (Wilson et al. 2018b) and they are generally disliked by people.

4.5 Feasibility of eradication

Eradication has been demonstrated for most of the 10 pest species considered here, but only on islands or within fenced sanctuaries, primarily because we currently lack the tools for their mainland eradication. Brodifacoum is the only toxin demonstrated to be effective, but it has strict limitations on its widespread use.

Because reinvasion is a major impediment to success, pest species' mobility, barriers to movement (e.g., rivers and mountain ranges), and rates of population recovery are important factors for eradication success and represent key knowledge gaps for managers. Rodents and mustelids have relatively high rates of population recovery, and large dispersal capabilities (e.g., Griffiths & Barron 2016; Bell et al. 2021), and can therefore reinvade over long distances (e.g., Carpenter et al. 2023).

Trapping and secondary poisoning of stoats can reduce stoat numbers significantly, but eradication on the mainland would be prohibitively difficult to achieve unless reinvasion can be stopped and every individual stoat removed. Feral cats are highly mobile and neophobic and there are currently no tools to eradicate them on the mainland. Also, the likelihood of eradicating feral cats is undermined by spill-over from the domestic and stray populations.

While rivers are good barriers to hedgehogs (Goodman 2024), hedgehogs' apparent high capture probability in traps has been refuted recently, with modelling showing that trapping alone is unlikely to achieve eradication in open landscapes (Goodman 2024).

Mice are a major challenge for eradication on the mainland because current approaches are of limited effectiveness (aerial 1080), have significant restrictions on their use (aerial brodifacoum) or require significant social licence and engagement, such as the requirement to access every building in the country. Mice might be the best candidate for genetic approaches in the future, but this technology, if it ever becomes a viable option, is some time (possibly decades) away.

There has been relatively little research or population control that has focused on weasels, Norway rats, or kiore. In contrast, possums have relatively small home ranges, low rates of population recovery, and do not cross low-flow rivers or high mountain ranges (Cook et al. 2021; Foster et al. 2022). It could be argued, therefore, that the prospects for eradicating possums are reasonably good (e.g., Nichols 2021), although this has yet to be demonstrated reliably on the mainland.

Given that gamekeepers in the UK eradicated polecats from an area approximately the size of ferrets' geographical range in New Zealand using 19th century traps and with no coordinated system for planning and monitoring their eradication, it seems likely that ferrets can be removed from large regions of New Zealand, if not the whole country, using modern technology. A ferret-free Northland, north Auckland, Coromandel, Taranaki, Tasman, and Golden Bay may be achievable but would require a combined research/operational strategy to optimise such a campaign. However, opposition and sabotage from farmers and ferret owners (see above) are likely to scupper such an initiative without an effective social marketing campaign.

Our high-level assessment of the feasibility of eradicating each species from the New Zealand mainland concludes that eradication is currently plausible for possums and perhaps ferrets using existing technologies. It is beyond current capability for mice, weasels, stoats, feral cats, hedgehogs, Norway rats, and ship rats (in increasing order of potential feasibility); and complex and indeterminate for kiore. It is important to note that a full assessment of feasibility is not a small undertaking, and the assessments offered in this analysis are only preliminary.

5 Recommendations

5.1 Address knowledge gaps that currently limit mainland eradication

The decision on which species to include in any revision of PF2050 targets will need to consider feasibility of eradication and the subsequent costs–benefits of their inclusion. In considering those criteria, a number of key knowledge gaps have emerged which, when addressed, will enhance eradication efforts against both the current species list and the others under consideration. While not excluding possums and ferrets, we recommend there should be a strong focus for research and development on stoats, weasels, Norway rats, ships rats, mice, feral cats, and hedgehogs. Key knowledge gaps that currently limit eradication prospects include the need to:

a refine and improve the current toolbox, with a particular emphasis on species/genus-specific toxins and, in the longer term, developing novel genetic and other technologies (effective traps, bait stations, baits, and other lures are also important components of an integrated system, particularly when mopping up individuals that may be resistant to core methods, and tools need to be humane, specific to mammalian predators, and effective across a range of habitat types)

b optimise species-appropriate deployment strategies, such as effective combinations of tools, tool site placement, density of tools, and timing and duration of deployment

c improved the detection and removal techniques of survivors and re-invaders at very low densities

d understand how animals use landscapes to inform the optimal distribution and density of devices for detecting and removing residual or invading individuals

e understand the benefits and/or negative consequences of removing, or significantly reducing the densities of, target species, particularly when not all predators are targeted locally

f develop integrated approaches, such as targeting trophic (feeding) relationships to 'supercharge' predator removal by controlling the target species' non-native food supply, both to reduce survival/productivity and to drive increased interactions with traps or toxic baits

g understand the ecological responses of less-studied indigenous biodiversity (bats, frogs, reptiles, and invertebrates) to the removal of predators.

The current landscape projects are ideal testing grounds for research, tool, and methodology development, and for monitoring low-density pest populations. Future investments on landscapes projects should be more strategic, with a focus on a formalised learning framework that will help the national strategy. We recommend a focus on fewer, more intensive, multi-species field eradications, ideally including inhabited island sites where reinvasion is preventable. A steering group (or groups) should be established to design the learning framework, ensure adherence to robust scientific principles and methodologies, and evaluate results at regular intervals.

5.2 Expand the species target list to include all 10 mammalian predators during the RD&I phase to 2030

Linklater and Steer (2018) and Leathwick and Byrom (2023) point out that the current narrow range of mammals on the list is less likely to deliver outcomes consistent with New Zealand's biodiversity goals compared to an approach that considers the full range of biodiversity threats. Expanding the current list to include mice, feral cats, and hedgehogs is a move in that direction, reduces the risks of perverse ecological outcomes, and opens up learning opportunities for their eradication.

In the case of mice, there is increasing evidence of their competitive and predatory impacts on a wide range of resources, such as plant seeds, and small-bodied invertebrates and lizards that other predators have difficulty accessing. As discussed earlier, mice can increase in size and abundance following eradication of predators or interspecific competitors (Rowe-Rowe & Crafford 1992; Cuthbert et al. 2016). Subsequently, their impact on indigenous species increases and after they reduce invertebrate abundance, they often switch to larger prey (Caravaggi et al. 2019; Duhr et al. 2019; Connan et al. 2024). Perverse outcomes in the form of increased mouse abundance after the removal of competition and predation has been observed at various New Zealand mainland sites (Clout et al. 1995; Goldwater et al. 2012) and offshore islands (Caut et al. 2007).

The problem, however, as already stated, is the lack of tools to achieve mouse eradication at landscape scales beyond aerial toxins (particularly brodifacoum), which have limitations on their use in many mainland environments. In the case of feral cats and hedgehogs, both consume large numbers of indigenous species, and cats, in particular, have been associated with significant impacts on prey populations, often leading to localised extinctions.

While there is less evidence of hedgehog impacts at the population level due to a lack of relevant studies, they probably represent a high risk to some indigenous species populations such as small endemic lizards (Jones et al. 2013). Early data from an intensive hedgehog removal programme on Kaitorete Spit, Canterbury, suggest that indigenous lizards are responding positively to the significantly reduced hedgehog numbers (T. Sjoberg, Predator Free Banks Peninsula, pers. comm.).

There are potential constraints related to including feral cats and hedgehogs in terms of economics (it will cost more), efficiencies (dilution of effort by expanding scope), system capacity (including insufficient capability), and social licence (some people have an emotional attachment to them, particularly cats). On the other hand, and as noted above, there are significant biodiversity risks resulting from removing only some members of the predator guild from a system, and there is no logical, objective argument beyond a current capability gap for excluding some predators, given the goal of protecting indigenous biodiversity and other social, economic, and cultural values.

Furthermore, giving managers the freedom to target all predator species without risking contractual or funder obligations could lead to improved learning and biodiversity outcomes, but this ought to be done under strict guidance from the above-mentioned steering group(s) to focus work on key knowledge gaps in a more structured and formalised way. The added advantage of including all 10 predator species on the target list by 2030 is the considerable cost-efficiencies of targeting them simultaneously (Griffiths et al. 2015; Samaniego et al. 2024).

Expanding the target list to 10 species extinguishes the risk of perverse ecological responses within the predator guild, but it raises the question of whether that risk warrants the extra expense. Feral cats and hedgehogs are unlikely to respond to removal of other predator species, so it is only the risk of mouse responses that is relevant here. However, it is difficult to quantify this risk because of the paucity of ecological studies and the fact that preliminary findings indicate responses are highly variable and dependent on food supply. The extra expense of mouse eradication has been assessed and considered to be a modest addition to the fixed expense of targeting rats (Samaniego et al. 2024).

We recommend signalling the intention to include all species considered here as targets in the PF2050 strategy review, with the caveat that, should the outcomes of the RD&I phase demonstrate that eradication is unfeasible for one or more species, the final list would be subject to confirmation ahead of the roll-out phase in 2030 and beyond.

5.3 Acknowledge the localised taonga status of kiore to some mana whenua

Kiore are a particular case in which management at place must consider and reflect local mana whenua values and perspectives. Although this suggests that arriving at co-management solutions risks being overly complex, the very limited distribution of kiore populations nationally means that a rohe-based approach to deciding whether kiore are a target species is feasible for island systems. The solution negotiated by DOC and Ngātiwai, where kiore are managed under kaitiakitanga on Mauitaha and Araara but were removed from other islands, could act as a model for place-based co-management in the other few areas where kiore are considered taonga.

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