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Review

Towards Ethical and Effective Conservation of New Zealand's Natural Heritage

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Abstract

Major human impacts on New Zealand's ecology began about 800 years ago with immigration firstly from Polynesia, then Europe starting a few centuries later. The humans cleared habitat, hunted species to extinction, and introduced biota, including plants, birds, fish, invertebrates, and mammals. Over the last 70 years, government-funded campaigns have been waged against some of the introduced mammals that became considered harmful to native biota. These campaigns spread poisonous food baits from aircraft to kill and suppress target animals (mainly brushtail possums (*Trichosurus vulpecula*) and rats (*Rattus* spp.)) over large areas. Increased intensity, frequency, and scale of poisoning are being trialled under a new conservation strategy (Predator Free 2050) to eradicate several mammalian species. The present study investigates the opportunity for a paradigm shift in conservation, emphasizing the rationales for transitioning from spreading of pesticides to a more targeted approach. NZ's poison- and predator-focused ecological management has been criticized internationally as cruel and unnecessary, while independent NZ ecologists have called for, and outlined, a new system of conservation management based on ecological knowledge, which embraces all threats to native biota. A central tenet of proposed new methods is the engagement of all relevant stakeholders. Efficient management tools include remote monitoring, and smart, self-resetting kill traps for targeted small mammal control. Ecology-driven, commercially sound, targeted, monitored, relatively humane management can be implemented to protect the remnants of NZ's natural heritage.

Keywords: New Zealand; conservation; aerial poisoning; ecology; monitoring; native species; 1080; sodium monofluoroacetate; brodifacoum; eradication; island restoration

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1. Introduction

A campaign against some of the mammals that were introduced to New Zealand (hereafter NZ) before the end of the 19th century began 70 years ago, using poisonous food baits sown by aircraft across large areas. The following provides evidence that the risks of this practice to native biota from poisoning and unwanted ecological effects and animal welfare concerns have not been rigorously addressed, then discusses how science-based, ethical conservation management can be implemented in NZ.

2. Background

2.1. Natural History

The terrestrial ecology of New Zealand, an archipelago of 892 islands in the South Pacific Ocean (latitude 33° S to 53° S, longitude 62° E to 173° W) evolved in long isolation, and without land mammals. The land split from the southern continent of Gondwanaland

about 83 million years ago, and thereafter immigrant species (which included bats) arrived only by wind and sea [1]. The two main islands were almost entirely covered in forest below the treeline [2]. Without mammals, birds and reptiles filled the ecological roles of large herbivores and their predators, and large flightless insects filled some of the usual rodent and lagomorph roles [1]. As a product of long isolation, 52% of its 54,000 named species are endemic [3].

2.2. Human Arrival

Major ecological changes occurred following the arrival of humans from Polynesia (Māori) circa 1280 CE, bringing the Pacific rat (kiore) (*Rattus exulans*) and dogs (*Canis familaris*) [1]. Over the next 500 years, with burning and hunting, the humans brought about a great number of extinctions, which included the dominant grazing species, the moa (Order Dinornithiformes), and eagles, hawks, waterfowl, and rails [1]. The kiore became widespread and probably caused the extinction of many small prey animals, including birds, lizards, frogs, and invertebrates, and may have altered the composition of forests through seed predation [4]. Māori also settled on and substantially modified many of NZ's small islands [5]. In the 1760s more animal introduction and hunting began with the arrival of European whalers and sealers, then accelerated after 1840, when New Zealand became a British colony [1]. At this time, much of the forest had already been cleared through burning by Māori—the east of the South Island and a third of the North Island was now largely grassland, fernland, or shrubland [2]. Exercising 'ecological imperialism' the Europeans established the animals and plants (and parasites and diseases) they had evolved with [1]. As a result of the introductions of plants and animals, the proportion of naturalized non-native species to native species exceeds nearly all other countries [6].

2.3. Aerial Control of Mammals

Thirty-two of the mammalian species introduced by the settlers became established in the wild in NZ [1]. Some became pests in agricultural and forestry operations, and some were condemned for their effects on the (perceived) natural environment [7]. Anti-mammal sentiment emerged strongly in the 1920s, driven by amateur botanist Leonard Cockayne who asserted that grazing and browsing by deer was highly destructive, and was joined by farmers, foresters, and botanical conservationists in starting, in the words of conservationist Bill Benfield, a government-funded "*official war against exotic wildlife*" [8] (p. 34).

Aerial poisoning was first used in conservation in 1956 when the NZ Forest Service started spreading cereal pellets laced with Compound 1080 (active ingredient sodium monofluoroacetate) from aircraft, targeting brushtail possums (*Trichosurus vulpecula*) [7]. During the 1960s and 70s, aerial operations were used to protect both planted and native forests from browsing possums, and from the early 1970s, possums were also targeted as a wildlife reservoir and vector of bovine Tb (*Mycobacterium bovis*, Tb) [7]. Aerial possum control was cut back in 1978, due to complacency regarding Tb, government austerity, and a spike in possum fur prices [9]; plus concern about the non-target poisoning of valued animals (native species, deer, dogs, and livestock), and uncertainty about whether possum browsing had in fact been damaging forests [7]. Funding for aerial control of possums resumed in the late 1980s [7], and in the 2000s the Department of Conservation (DOC, responsible for conservation management since 1987) increasingly used aerial poisoning to quell rapidly growing rat populations (mainly ship rats, *Rattus rattus*) and attempt to control their predator, the stoat (*Mustela erminea*) via secondary poisoning [10]. Aerial poisoning for 'suppression' of pests needs to be repeated at intervals due to repopulation, which can be very rapid with rats [11]. In the year to June 2024, over a million hectares

on NZ's North and South Islands were aerially sown with poisonous baits targeting rats, mustelids, and/or possums for conservation purposes [12] (p. 173).

Under a planned new conservation strategy, Predator Free 2050 (PF2050) (introduced by the Government in 2016), a suite of mammals is to be eradicated (Table 1) [13,14].

Table 1. Mammals targeted for eradication by 2050, with approximate date of establishment in NZ ([1] may be removed from the list; [2] Rakiura, possibly all NZ; [3] possibly North and South Islands (not known to be established on Rakiura) [14].

Common Name	latin Name	Date Established in NZ *
Pacific rat (kiore) [1]	*Rattus exulans*	1280
Feral cat [2]	*Felis catus*	1769
Norway rat	*Rattus norvegicus*	Late 1700s
House mouse [3]	*Mus musculus*	By 1824
Hedgehog [2]	*Erinaceus europaeus occidentalis*	Late 1800s
Brushtail possum	*Trichosurus vulpecula*	1858
Ship rat	*Rattus rattus*	By late 1800s
Ferret	*Mustela furo*	1870s
Weasel	*Mustela nivalis vulgaris*	1883
Stoat	*Mustela erminea*	1883

* From separately authored chapters in The Handbook of New Zealand Mammals: rodents [4], cat [15], hedgehog [16], possum [17], and mustelids [18].

To inform the programme, an increased intensity of poisoning, intended to kill all targets, has been under trial in South Westland across 107,000 ha [19,20]. Two aerial 1080 operations are used, the first using a double sowing density of baits. The landscape is "pre-fed" twice with non-toxic baits to get animals used to eating them. Following the operations, smaller-scale follow-up aerial 1080 operations, bait stations (including brodifacoum baits), traps, and hunting are used to remove survivors and invaders [20].

On NZ's third largest island, Rakiura (175,000 ha), the "Predator Free Rakiura" programme aims to eradicate possums, the three species of rat, feral cats, and hedgehogs [21]. Aerial poisoning using 1080 cereal baits is beginning across 43,000 ha in winter 2025. Within the poisoned area there will be a trial eradication zone using an extra poisoning and pre-feeding regime [21,22].

Many of NZ's smaller, uninhabited islands have been aerially sown with brodifaoum-laced rodent baits to eradicate mammals, mostly rodents [23]. The practice began in the 1980s, then numbers of operations surged in the 1990s (including many targeting kiore), and operation scale has gradually increased [23]. Following the successful eradication of mice from the relatively large Antipodes Island (2100 ha) in 2016, the much larger Auckland Island (46,000 ha) is to be targeted next [24]. Under PF2050, more island eradications will be carried out (technique not specified): "*A 2030 goal: Predator eradication is complete or underway across 75% of New Zealand's offshore island network area* [14]." (p. 19).

2.4. The Aerial Poisons

Compound 1080 (active ingredient sodium monofluoroacetate) acts by blocking respiration within cell mitochondria, and is harmful to a broad range of organisms, e.g., bacteria, fungi, plants, nematodes, snails, insects, birds and mammals [25], (Appendix N pp. 721–759 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/723b6c26b6/HRE05002-043.pdf accessed on 1 August 2025) [26]. It has marked abilities to spread in water and food chains [25] (Appendix C, pp. 348–431 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/9917ed4348/HRE05002-054.pdf accessed on 1 August 2025). Sub-lethal effects seen across a wide range of species include damage to reproductive

structures, birth defects and organ damage [25] (Appendix B, pp. 293–345 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/b1389a596e/HRE05002-055.pdf accessed on 1 August 2025). Effects can be cumulative in some animals (e.g., dogs, rabbits) but exposure can lead to tolerance in others (e.g., mice, rats) [27]. Sub-lethal effects of 1080 on birds include damage to testicular morphology [28] and heart and wing muscles [29]. The high energy requirements of avian muscle tissue may make it particularly susceptible to 1080 [29]. Breakdown of 1080 in the environment can take months, especially in cold or dry conditions [30], and in poisoned carcasses, it can persist for months [31] and perhaps indefinitely if the carcass has dried [7]. Breakdown products include hydroxyacetic acid, carbon dioxide, fluoride ions, fluorocitrate (toxic) and fluoromethane [32,33].

Brodifacoum is a common, slow-acting poison used for rodents that is also toxic to birds, fish, reptiles, invertebrates, algae and microorganisms [34–39]. Due to its high toxicity to freshwater crustacean *Daphnia magna*, brodifacoum was rated highly toxic to aquatic organisms [35], and after devastating land snail (*Pachnodus fregatensis*) numbers, was termed a "molluscicide" [36]. In vertebrates, it interferes with the synthesis of clotting factors, whereas the toxic mechanism in invertebrates is unknown but possibly involves a collapse in osmotic balance [40]. Fatally poisoned mammals undergo severe to extreme suffering for days to weeks (compared to severe suffering for hours to days with 1080) [41]. The effects of sub-lethal brodifacoum exposure on survival or reproductive fitness are not known [42]. Brodifacoum spreads and persists for months to years within food chains, soil and sediment [43]. Mechanisms and pathways of degradation are not well described [42]. Due to its potential to harm non-target animals, the EU recommended that brodifacoum should only be used in and around buildings, with limited periods outside in bait stations that were protected from other animals [38]. Globally, there is environmental transfer of anticoagulants such as brodifacoum through trophic pathways, in both terrestrial and marine environments [44,45].

The poisoned baits (sometimes carrot, usually cereal made by a government-owned company (Orillion)) are distributed from a spinner bucket slung beneath a helicopter (Figure 1). Bait fragmentation [46,47], dust [48] and leaching (of 1080 [49]) can assist the dispersal of the toxins, increasing the risk to untargeted species. Minor waterways, shorelines (Figure 2) and offshore rock stacks are likely to harbour target animals and can be included (e.g., [50,51]). Supplement Document S1.



Figure 1. Helicopter-borne buckets fitted with a spinner are used to spread the poisonous baits, August 2014, Tongariro. Photo credit: Steve and Clyde Graf.



Figure 2. Warning sign for 1080 poison positioned on the beach of Lake Taupō, 2015. Photo credit: Clyde and Steve Graf.

3. Oversight of Aerial Poisoning

3.1. The Department of Conservation

Under the Conservation Act (1987) the DOC is required to preserve "*natural resources*," defined as "*plants and animals of all kinds, systems of interacting living organisms, and their environment*." Under the Reserves Act (1977) the DOC is responsible for the "*survival of all indigenous species of flora and fauna, both rare and commonplace, in their natural communities and habitats, and the preservation of representative samples of all classes of natural ecosystems*." The national biodiversity strategy Te Mana o te Taiao also requires ecosystems to be protected [52].

In the DOC's 2024 Annual Report, under "*Strategic Outcome: Ecosystems and species across Aotearoa are thriving from mountains to sea*" there is no record for ecosystems for the three-year period from 2022 to 2024, with a footnote excusing the 2024 omission [12] (p. 175). Concerns were raised in 1999 that the ecological outcomes of aerial poisoning with 1080 were going unmeasured. Dr. John Innes and Gary Barker from the government-funded research organization Landcare Research warned that, "*Scientists have not examined the net ecological outcomes . . . key conservation legislation demands that [managers] do so . . . we suggest that priorities are to measure net ecological outcomes at the community level, to reduce toxin use, and to improve pest control strategies and techniques*" [53] (p. 111). Six years later Innes stated: "*Net outcomes (the balance between so-called 'costs' and 'benefits') of rodent population control must be measured at the community level, because non-target deaths, secondary poisoning, diet switching, and other unexpected responses may counter-intuitively negate the benefits of reducing ship rat numbers*" (Innes, 2005) [54] (p. 203). In 2023, an historic and ongoing lack of outcome monitoring was noted by independent (ex-Landcare Research) ecologists Drs. John Leathwick and Andrea Byrom (citations removed): "*Current predation management frequently assumes positive biodiversity outcomes, yet fails to test hypotheses . . . that would determine the mechanisms behind observed biodiversity responses. Further, experimentally robust assessments of actual outcomes are rare . . . For example, we found just one published account of long-term monitoring (defined as >10 years or three or more 1080 cycles) of a rat-vulnerable bird species following repeated aerial 1080 applications . . . current landscape-scale projects conducted under the*

umbrella of PF2050 are yet to publish any quantitative assessments of native biodiversity responses to predator eradication" [55] (p. 7).

The DOC has carried out monitoring of several bird species in association with its poisoning operations using four techniques that may all produce misleading results, as follows. 1. The five minute bird count, the DOC's longstanding method of assessing bird populations [56], is unreliable [55–59]. For instance, calling of individual survivors can increase after poisoning [60] such as when birds search for dead or new associates or establish new territory. Moreover, bird count assessments have tended to be confounded by additional management including trapping and ground-based poisoning, such as in the Eglington [61] and Landsborough Valleys [62]. 2. Nesting success (production of fledglings) is also confounded: increased success has been interpreted as a beneficial effect (e.g., [63], (pp. 13, 114, 28)), but it may be a consequence of populations being severely culled [64,65]. For instance a population of tomtits (*Petroica macrocephala*) estimated to have been culled by 79% by an aerial 1080 operation showed enhanced nesting success the following season, with pairs rearing two, and even three broods [66]. 3. Monitoring of nests (e.g., climbing into tall trees to inspect parakeet (*Cyanoramphus auriceps*) nests regularly [67]; climbing into kea (*Nestor notabilis*) nesting cavities repeatedly, handling chicks and leaving cameras behind in the cavity [68]; taking blood samples from dotterel chicks (*Charadrius obscurus obscurus*) [69]; and even just installing cameras in nest trees to view riflemen (*Acanthisitta chloris*) [70] all have high potential to accentuate or artificially create circumstances for predation by attracting aerial and ground predators and disrupting the birds themselves [71–75]. Stoats (and other predators) have been observed to follow a nest researcher around [74] and will kill and cache surplus prey [18] therefore a single stoat could potentially wreak havoc in a series of monitored nests. 4. Attachment of radio telemetry monitoring equipment, for instance, to nesting adult kiwi (Fiordland tokoeka (*Apteryx australis australis*)) and their chicks to determine whether stoats preyed on them [76]; to nesting kea in Arthur's Pass National Park to determine whether newly invading cats ate them (they did not [77]); and to near-fledging kea chicks to see whether they survived [68] can disadvantage the birds in many ways [78,79], again creating artificial vulnerability (as well as animal welfare concerns) [80,81].

3.2. The Reassessment of 1080 by the Environmental Risk Management Authority

In 2007, a major reassessment by the Environmental Risk Management Authority (ERMA) gave official approval for continued, increased aerial spreading of 1080 poison [82]. The review identified many risks and a lack of information on many topics. The main users (the DOC and the Animal Health Board, the 'Applicants') had been required to re-apply to the ERMA to use 1080, under the Hazardous Substances and New Organisms Act (1996). The ERMA's Agency evaluated the evidence put forward by the Applicants and wider sources of information, and reported to its Committee.

A detailed examination of the ERMA's reassessment indicated it may have fallen short of its legal obligations in several ways: there was a lack of reliable information (e.g., Table 2) and verification; a lack of objectivity; the Māori consultation was criticized as inadequate; and some issues that went unaddressed included those raised in reviews by its own commissioned experts on economics and animal welfare, plus the risk of uncontrollable spread, as well as scientific criticism ([83], unpubl.; this reference provides tables of direct quotes from the ERMA documents that address each legal shortfall, for the reader to examine then verify in context in the documents themselves). Supplement Document S2.

Table 2. Subjects relevant to ecology for which there was no, or little, information found in the Environmental Risk Management Authority's reassessment of 1080 in 2007 [25]. "*Data gaps*" refer to no "*definitive*" studies (carried out in accordance with international guidelines) [25] (Appendix C, p. 349 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/9917ed4348/HRE05002-054.pdf, accessed on 1 August 2025). The ERMA's Decision Path for importing or manufacturing a hazardous substance asked: "*Is this information sufficient to proceed? If no, seek additional information, if still not sufficient, do not approve*" [25] (Appendix A, p. 290 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/c0daf928da/HRE05002-056.pdf accessed on 1 August 2025).

Effect	Page No. [25]	Wording
Adsorption/desorption in a range of soils	349	"*Data gap*"
Reproductive toxicity to birds	349	"*Data gap*"
Toxicity to frogs	723	"*The Agency has made no assessment of risks to frogs*"
Toxicity to algae	349	"*Data gap*"
Toxicity to aquatic invertebrates	349	"*Data gap*"
Chronic aquatic toxicity	349	"*Data gap*"
Biodegradation in aquatic systems and soils at varying pH, soil type and temperature	349	"*Data gap*"
Toxicity to terrestrial invertebrates	350	"*Data gap*"
Toxicity of the breakdown product fluorocitrate in water or soil	360	"*The applicants did not provide, and the Agency was not able to locate, any data . . .*"
Toxicity to native NZ reptiles	416	"*No data are available . . .*"
Adsorption/desorption or leaching of 1080	349	"*No standard guideline studies . . . were submitted . . . or located by the Agency*"
Reversibility of effects on the male reproductive system	294	"*data on 1080 that would be desirable*"

A detailed scientific review of the evidence put forward by the Applicants to support the aerial use of 1080 was submitted to the ERMA by highly qualified, retired scientists Drs. Pat and Quinn Whiting-O'Keefe [25] (Appendix T, p. 852 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/f4a5dc50f6/HRE05002-037.pdf, accessed on 1 August 2025). Supplement Document S3. Among their conclusions were, "*Repeatedly dropping food laced with 1080 indiscriminately into a forest is an ecosystem level intervention that would be expected to have a wide range of effects on flora and fauna. Yet not one 'Control level 1' or better study has been done at ecosystem level. . .*

"We do not know the degree to which possums negatively impact populations of native floral species, and we do not know if aerial 1080 ameliorates the damage. Possums undoubtedly 'prey' upon native forests, but the net effect of that predation, the degree to which it can and should be reversed, is far from clear. Even the flawed and biased studies present a confused and inconsistent picture. . .

"Therefore it is impossible to make a rational decision about whether the a priori risks and the empirically proven risks of aerial 1080 are justified by the benefits".

Other issues that arose in the ERMA reassessment were the potentials for unreliability in sampling to assess environmental contamination [84] (p. 119) (Supplement Document S4)

and chronic poison exposure due to carcasses in waterways [25] (Appendix M, p. 700 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/475377593c/HRE05002-044.pdf, accessed on 1 August 2025). Variability in effects of 1080 ([84], unpubl.) and unexpected findings ([85], unpubl.) (Supplement Document S5) were a characteristic of the 1080 research the ERMA reviewed. Notably, "*The sensitivity of a species to 1080 poison is difficult to predict from toxicity data from other, closely related species*" [86] (p. 119).

A new control imposed by the ERMA in 2007 requiring more monitoring was not made enforceable. The new requirement differed between the main text of the Committee's Decision and the fine print it referred to, as follows: "*. . . the Committee is imposing a control requiring information about each aerial operation . . . in general terms the information must include . . . details of pre- and post- monitoring of fauna . . . details of post-operation monitoring of water quality*" [82] (p. 92). However later in the same document it states, regarding the details of the new control, that any person who applies aerial 1080 must supply information on "*. . . pre- and post-operational monitoring of birds and invertebrates (if available) . . . and water quality (if available)*" [82] (pp. 188–189).

Brodifacoum is to be reassessed by the same agency (now called the Environmental Protection Authority) in 2027 [87].

3.3. Report on 1080 by the Parliamentary Commissioner for the Environment, 2011

NZ's Parliamentary Commissioner for the Environment (PCE) provides the government with independent investigations and reviews on environmental matters (Environment Act 1986, Section 16). In 2011, the then PCE Dr. Jan Wright wrote a favourable report on 1080 poison that concluded more poisoning was needed [88]. This contrasted with a previous PCE's conclusions that its long-term use was inadvisable [7]. Some claims of the benefits and harmlessness of 1080 made in the 2011 report appear to be not well supported by the scientific evidence given ([89], unpubl., Supplement Document S6, [90,91]); examples are provided below in Section 6 on animal welfare.

4. Poisoning of Native Species

4.1. 1080

There is evidence that aerial 1080 poisoning operations result in the mortality of some indigenous fauna. However, there is a lack of comprehensive data. The DOC provided only a "*very brief*" report on non-target animal monitoring in its application to the ERMA in the 2007 reassessment of 1080 [25] (Appendix F p. 480 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/53e966a313/HRE05002-051.pdf, accessed on 1 August 2025). In addition, the relevance of historic data on death rates is questionable where practices have changed (e.g., sowing rates and the adoption of pre-feeding with non-toxic bait) [92]. In 2016, Landcare ecologist Dr. Phil Cowan and others noted the ongoing vulnerability of native birds to 1080, due to bait repellents being ineffective, the minute amount of bait required to kill small birds, and the likelihood that birds would eat fragments of baits and peck at whole baits [93]. Small fragments are a problem with both carrot [46] and cereal baits [47].

Twenty-one species of native birds have been listed as found dead in areas poisoned with 1080 [25] (Appendix C https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/820e9f2059/HRE05002-004.pdf, accessed on 1 August 2025) [94,95]; Figures 3–5. Ecologist Dr. Eric Spurr commented, "*It is clear from the available evidence that species with good reproductive and good dispersal capacities have the ability to recover from even a large reduction in numbers. It is equally clear that species with both poor reproductive and poor dispersal capacities have only a limited ability to recover*" [94] (p. 59).



Figure 3. The kea, *Nestor notabilis*. At Matukituki in Mt. Aspiring National Park and Wet Jacket Peninsula in Fiordland National Park, 50% of monitored kea died following 1080 poisoning operations. The total number of kea remaining is unknown [96], however estimates as low as 1000 individuals have been made since 1986 [97]. Kea are considered to have "*an extraordinary, alien intelligence*" [98] (p. 1). Photo credit: Clyde and Steve Graf.



Figure 4. Stills from video footage of an endemic species, the weka (*Gallirallus australis*), 2016, documenting an example of possible secondary poisoning as: (**A**) weka discovers carcass of rodent poisoned by 1080; (**B**) lifts the contaminated animal from the forest floor; and (**C**) carries it away. Photo credit: Clyde and Steve Graf.

Some of the DOC's monitoring of poisoning outcomes has used radio-transmitters attached to birds. These studies have found some particularly high percentages of monitored kea (*Nestor notabilis*) confirmed as dead from 1080 poisoning: 50% at Matukituki in Aspiring National Park [99] and at Wet Jacket Peninsula in Fiordland National Park [100]. The method recorded a mortality rate of 9.4% for fernbirds (*Megalurus punctatus*) [101]. Radio-transmitter-wearing North Island Brown Kiwi (*Apteryx mantelli*) were reportedly unaffected by poisoning [102], however two dead kiwi (species not given) tested positive after a poisoning operation at South Okarito, Westland in 2022 [103] (1080 was not recorded as the cause of death).

Evidence of secondary poisoning from 1080 was discovered accidentally in a study on lesser short-tailed bats (*Mystacina tuberculata*) after an aerial 1080 operation, where the

contents of a roost tree had spilled onto open ground. The debris contained a dead baby bat (with its placenta attached) that tested positive for 1080 [104].



Figure 5. (**A**) A protected endemic species, the New Zealand robin (*Petroica australis*) pecks at a cereal bait poisoned with 1080, 2015, Pureora; (**B**) A grey warbler (*Gerygone igata*) found dead after 1080 operation in Kahurangi National Park, 2008. Photo credit: Clyde and Steve Graf.

Recording of any native animal deaths was only "*incidental*" in research in Westland using the new, intensified 1080 poisoning regime for eradicating multiple 'predator' species [15] (p. 2). In November 2021, over 550 poisoned native black-backed gulls (*Larus dominicanus*) were discovered on the beaches of a Westland river. The DOC stated that these gulls, "*were previously not known to be present in such high numbers in the area*" and assured the public that, "*The incident has been recorded . . . so that those planning and assessing future operations in potential karoro habitat are aware of the risk to the birds and can mitigate that risk appropriately*" ([105], unpubl.) (Supplement Document S7) (response to Official Information Act request, 18 March 2022). However, the following year, more of the gulls were poisoned [106]. Not formally monitoring wastes valuable opportunities to learn: "*The lack of robust, hypothesis-driven assessment of native species' responses or adherence to basic principles of good experimental design makes it difficult to critically test assumptions behind predation-focused management, or to quantify the biodiversity gains it delivers relative to cost*" [55] (p. 7).

Knowledge of how invertebrates such as kōura (freshwater crayfish, *Paranephrops* spp., Figure 6), molluscs or insects are affected by aerial 1080 poisoning is limited. Negative

effects might be expected on insects given that 1080 was first trialled as an insecticide (patents taken out in 1927 and 1946) and found to be effective on fleas and aphids as a secondary poison (administered to rats, and plant leaves, respectively), however it was deemed unsuitable for commercial use due to its high toxicity and persistence [107]. A review published by NZ entomologist Dr. Peter Notman in 1999 advised, "*The impact of 1080 on invertebrates is likely to be far-reaching, considering both the wide range of invertebrates reported as being susceptible to 1080 and the variety of microhabitats in which 1080 is available to insects . . . 1080 should not be used where susceptible invertebrate species or rare insectivores are found*" [108] (p. 69–70).



Figure 6. Two kōura (freshwater crayfish, *Paranephrops* spp.) seemingly compete for a poisonous cereal bait, 2016. Photo credit: Clyde and Steve Graf.

Field studies on invertebrate populations have shown indications of negative effects of 1080 [25] (Appendix F, p. 510 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/53e966a313/HRE05002-051.pdf, accessed on 1 August 2025) [109], [Suren and Lambert cited in [25]] (Appendix C, p. 192 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/820e9f2059/HRE05002-004.pdf, accessed on 1 August 2025) [110–112] that have not been followed up. An experiment carried out by the DOC in winter/early spring at Ohakune (588 m a.s.l., on the North Island's Central Volcanic Plateau) on invertebrates in the vicinity of 1080-toxic and non-toxic baits has been cited as evidence that 1080 has little effect on reducing numbers of invertebrates—only as far as within 20 cm of the baits (e.g., [88]). But a significant reduction in invertebrate numbers was also evident 100 cm from the baits, and effects on invertebrates became even more marked after a second lot of toxic baits was distributed nine days after the first [109].

The effects of 1080 baits on invertebrates were identified as a "data gap" in the 2007 reassessment of 1080 by the ERMA, due to a lack of qualifying research [25] (Appendix C p. 350 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/9917ed4348/HRE05002-054.pdf, accessed on 1 August 2025). Laboratory studies viewed by the ERMA [25] (Appendix C https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/9917ed4348/HRE05002-054.pdf, accessed on 1 August 2025) included one on native cockroaches (*Celatoblatta undulivitta*, *C. vulgaris* and *C. subcorticaria*) in which most died within 2 weeks of exposure to 0.08% 1080 cereal baits; one on aphids feeding on broad bean plants, which died when the plants were grown in 0.00005% 1080 culture solution; and findings that both mosquito larvae (*Anopheles quadrimaculatus*) and wasps (*Vespula vulgaris*) were readily killed by 1080.

4.2. Brodifacoum

Monitoring of the effects of eradications on island fauna has largely concerned birds [113,114] and many eradication projects have involved little formal pre- and post-monitoring, as pointed out by Dr. Erika Zavaleta in 2001 at the International Conference on Eradication of Island Invasives (pointing to some of the contributions from other attendees as examples) [115]. Within NZ, very high losses following aerial brodifacoum operations have been recorded for some bird species, for example, 98% of Western Weka (*Gallirallus australis australis*) on Chetwode Island and 90% of pukeko (*Porphyrio melanotus*) on Tiritiri Matangi Island [116]; nearly all fernbirds (*Bowdleria punctata wilsoni)* on Codfish Island [117]; 60% of paradise shelducks (*Tadorna variegata*) on Motuihe Island [118]; and 50% of New Zealand dotterels (*Charadrius obscurus aquilonius*) at Tawharanui National Park in the North Island [119].

Observations of before versus after poisoning populations of some native species were made around the mouse eradication carried out in winter 2016 on the Antipodes Islands (in the Southern Ocean, 733 km SE of NZ), where research was ongoing. The mice had occupied the island since perhaps 1908 [120]. Three "key indicator" species were chosen for formal monitoring: the Antipodes Island pipit (*Anthus novaseelandiae steindachneri*), the Antipodes Island parakeet (*Cyanoramphus unicolour*) and Reischek's parakeet (*Cyanoramphus hochstetteri*). Dramatic losses were recorded for pipits and Reischek's parakeets, from estimated densities of 3.2/ha to 0.2/ha, and 3.2/ha to 0.6/ha, respectively. The number of Antipodes Island parakeets was already low, and they appeared to undergo a decline, with numbers dropping from 0.5/ha to 0.3/ha. These bird populations apparently recovered over the following five years (although interpretation of bird counts was confounded by possible seasonal effects [120]).

Secondary poisoning from aerially delivered brodifacoum baits was observed on Ulva Island sanctuary in 2011. Approximately 1/3 of the robins (*Petroica australis rakiura*) died [121] and three to four months later, dead nestling robins were found, apparently poisoned by invertebrates fed to them by their parents [122].

5. Unwanted Ecological Outcomes

Monitoring of numbers of the targeted pests has shown there are large ecological repercussions from aerial 1080 operations. Usually, rat and possum numbers are reduced to low levels, increased numbers of mice (*Mus musculus*) often appear, followed a few months later by increased numbers of ship rats (often growing to exceed pre-poisoning levels), and sometimes stoats [123–126]. Such increases may harm populations of the animals' prey [127,128]. For example, Sweetapple & Nugent reported in 2007: "*In the poisoned block, the number of large invertebrates known to be eaten by rats soared after rat numbers were reduced to near zero, and then plummeted as rat numbers exploded to very high levels. In contrast, in the unpoisoned area, the numbers of rats and of the common large invertebrates remained more or less stable*" [129] (p. 9).

Stoats are not always killed in aerial 1080 operations and their subsequent predation on native fauna can increase dramatically, as reported by King & Murphy in 2005, "*. . . rats were the main prey of stoats . . . After successful poison operations against rats, there were strong and consistent responses by stoats to eat more birds*" [130] (p. 270) and the DOC in 2002, "*Four months after an effective possum and rat knock-down by a 20,000-ha aerial 1080 operation over Tongariro Forest, stoats reappeared in the centre of the forest and began killing kiwi chicks. So far five of the 11 chicks have been predated, and all in the centre of the treatment area*" [131] (p. 90).

Ecosystem-scale impacts of aerial brodifacoum poisoning eradications on islands have not often been comprehensively monitored (with evaluations most likely to focus on rodent-vulnerable species likely to benefit [132]), but observed outcomes of eradications

have included negative effects such as invasive plants recovering from herbivory and invasive birds recovering from predation [114,115,132]. Five years after the Antipodes Islands mouse eradication, introduced dunnocks (*Prunella modularis*), which were very uncommon before the eradication, had become very common: "*many tens of dunnocks were seen and heard every day*" [120] (p. 11). The researchers suggested the "*predatory void left by mice was taken over by other bird species including exotic passerines*" [120] (p. 12). Negative effects of eradications are more likely where the introduced, newly eradicated species had previously replaced a functionally important native species, and in ecosystems containing multiple introduced species [115,133]. Unwanted effects can occur regardless of eradication technique: on Fiordland islands, where Norway rats and/or stoats were removed using ground control several decades ago, native robins have flourished, seemingly aggressively ousting other native bird species [134].

Major effects on native invertebrate populations were noticed in casual observations after the 2016 Antipodes Islands aerial brodifacoum poisoning. The endemic fly (*Xenocalliphora antipodea*) became "*obviously more abundant in January and February than it had been before eradication, and it was even more abundant in 2018 and 2019*" [120] (p. 7). An unidentified native noctuid moth, with a big caterpillar that had been observed only once before the poisoning, had a "*large emergence*" in 2018 with "*conspicuous*" numbers of its caterpillars during the summer and elevated numbers had persisted in 2021 [120] (pp. 7–9). Another surprise was that plants (*Hebe salicifolia* and dock *Rumex obtusifolius*) had been accidentally introduced (later removed) at a hangar and hut site, respectively, despite rigorous biosecurity management [120].

Three years after rat eradication on Kapiti Island, a pitfall trapping study found a significant decrease in invertebrate catch frequency and diversity, which were suggested to be related to dramatic increases in bird numbers [135].

6. Animal Welfare Impact

Animal ethics expert Dr. Mark Fisher was engaged to provide expert opinion to the ERMA for its reassessment of 1080 in 2007. He wrote, "*1080 presents a significant welfare risk- poisoned animals experience several hours of compromised welfare and death, and possible pathological effects in surviving animals. This risk, not just to possums but many other species, should be acknowledged and considered in an assessment of 1080. Given that 1080 is a broad-spectrum toxin, it is essential that the broad spectrum of costs and benefits is considered and not just limited to possums*" [25] (Appendix I, p. 574 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/e476596794/HRE05002-048.pdf, accessed on 1 August 2025). This point was also raised by submitters the RNZSPCA and the National Animal Welfare Advisory Committee [25] (Appendix T pp. 886-887 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/f4a5dc50f6/HRE05002-037.pdf, accessed on 1 August 2025). However, the ERMA Committee's Decision regarding animal welfare concerned only targeted pests: "*Work is being done on the improvement of bait to ensure that a lethal dose is delivered to the target animal. This is consistent with the Authority's ethical framework which requires that account be taken of concern for animal welfare*" [82] (p. 83).

In 2011, animal welfare issues were again not rigorously addressed in an official review ([89], unpubl., [90,91]) (Supplement Document S6). In that year's PCE Report on 1080 (Section 3.3, above) it was stated that research by Dr. Ngaio Beausoleil and others from Massey University [41] had rated 1080 as "*moderately humane*" for killing pest animals [88]. Those researchers had actually deliberately dropped use of the term "*humaneness*" and replaced it with "*animal welfare impact*". They stated 1080 caused an impact lasting for hours, and rated it as "*intermediate*" on a scale with cyanide (rapid loss of consciousness and death) at one end, and brodifacoum (severe to extreme impact for days to weeks) at the other end.

The behaviour of poisoned possums was not comprehensively covered in the 2011 report which provided a quote from a single document, which stated they "*stop eating within an hour of consuming 1080, become lethargic and die between 5 and 40 h later, depending on the dose consumed*" [88] (p. 52). Reports not cited described, "*Normal behaviour and feeding first 1–29 h after dosing, followed by hypersensitivity to noise or movement; lethargy; shallow respiration, poor coordination and balance, brief convulsions, squeaking* . . . (death after 5–97 h)" [McIlroy cited in [25], (Appendix C, p. 393 https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/9917ed4348/HRE05002-054.pdf, accessed on 1 August 2025); *retching* . . . *vomiting* . . . *incoordinated* . . . *intermittent myoclonic spasms* . . . *repeated episodes of tremors, leg paddling* . . . *in five possums this activity increased in duration and severity so that it resembled a grand mal seizure* . . . *possums were sometimes propelled into the air or along the floor by these movements* . . . *Five lethally dosed possums vocalised during spasms, tremors or seizures. In two of these animals, it was loud and prolonged or repetitive during an episode [136] (p. 63).*" The suffering of offspring also needs to be considered—for instance female possums can be found dead with still living, dependent young (see Supplementary Material Figure S1).

The 2011 PCE report noted that "*some people are particularly concerned about the accidental deaths of dogs from 1080*" [88] (p. 46). Dogs are extremely sensitive to the poison [32] and frequent accidental victims due to scavenging within and sometimes far beyond poisoned areas [106], the suffering appears intense: "*the spasm period of victims, particularly the canines, seems unduly violent* . . . *The severe spasms associated with 1080* . . . [are an] *outstanding objection*" [137] (p. 106). Carcasses may possibly remain toxic indefinitely [7,31], creating an ongoing risk wherever 1080 has been used.

Deer poisoned by 1080 often have bloodshot eyes, bloody foam around the muzzle, and the appearance of having undergone prolonged thrashing [138] (see Supplementary Material Figure S2).

Brodifacoum causes more prolonged and extreme suffering in birds and mammals than other poisons, due to adverse physiological effects associated with impaired blood coagulation, with the primary cause of death being severe internal bleeding occurring over a number of days [44].

NZ's aerial poison spreading has been criticized by prominent international scientists as unethical. Dr. Marc Bekoff, professor emeritus of Ecology and Evolutionary Biology at the University of Colorado wrote in 2020, "*New Zealand's continuing war on wildlife is one of the most inhumane assaults on nonhuman animals and a wide variety of pristine landscapes, air, and water*" [90] (p. 1). Ethicist Dr. Koen Margodt of the Jane Goodall Institute, Belgium, at Dr. Goodall's request, made a detailed investigation into NZ's use of aerial poisoning and its Predator Free 2050 strategy. His report was provided to the NZ Government [91]. Margodt stated "*This eradication programme causes a prolonged death agony of intense suffering for millions of animals. Besides target animals such as possums, rats and stoats, poison victims also include native endangered birds, farm animals and companion animals, in particular dogs*" [91] (p. 19). He considers aerial poisoning and Predator Free 2050 "*unethical, unnecessary and unrealistic*" [91] (p. 1). Dr. Jane Goodall's words were, "*There are more humane ways of dealing with 'invasive species' than 1080*" [90] (p. 1). Ironically, animal welfare has been used to justify intensive poisoning for eradication, on the basis that on-going control can cause on-going suffering [44], however this argument depends on the control technique [139].

7. The DOC's Reasons for Aerial Poisoning

7.1. Masting

A predominant rationale proffered by the DOC for using aerial 1080 poison is that native beech tree (*Nothofagus* spp.) masting or synchronized intermittent seeding, results in 'predator plagues' of rats and their predator, the stoat. According to the DOC's reasoning,

these animals necessitate quelling with poison to avert their predation on indigenous animal populations [140]. However, it should be noted that:

- The aerial poisoning method of control is likely to result in escalation in the population sizes of mice, rats and possibly stoats (see above), which is the scenario that the poisoning is intended to avert;
- A wide array of plant species exhibit masting, with differing temporal patterns and variable responses from rodents [126,141–143];
- In the context of beech forests, increases in the populations of mice have been observed following masting events [144] and the effectiveness of aerial 1080 in controlling mice can be poor [145];
- Aerial 1080 has been unreliable in controlling stoats, which can switch to eating birds when rats suddenly become scarce [131,146];
- Masting is natural and the short-term seed surpluses likely caused rises in numbers of original species occupying the rodent niche (e.g., Orthopterans [1]), and in turn, supported predators. Rodent effects began over 700 years ago with kiore and included phases of high numbers [147] (pp. 45–46);
- Bird productivity has been observed to increase following masting and such increases may offset any increased predation [67];
- Fears that a mast-driven stoat plague would devastate birds in the Murchison Mountains turned out to be unfounded—when the food supply (mice) crashed, stoats shifted to eating ground weta (*Hemiandrus* spp.) rather than birds [148];
- In poisoning deaths, or if reproduction is harmed through sub-lethal exposure, genetic material (along with the potential to adapt, e.g., to predation pressure [128]), is lost from endemic populations;
- An analysis of ship rat, mouse and mustelid tracking between 2005 and 2022 indicated that historic aerial management operations had magnified ship rat irruptions in subsequent mast seeding events in pure and mixed beech forests [106] (p. 44);
- Annual reports on mast-based management in the Eglinton Valley in Fiordland since 2016 onwards show aerial poisoning has been supplementary to ground based poisoning and trapping. Recent outcomes have included the need for additional "inter-mast" aerial poisoning; high peaks in numbers of stoats; a substantial presence of rats, mice and weasels; poorly controlled cats; and the prized mohua (*Mohoua ochrocephala*) bird population just holding on following multiple, substantial population top-ups with birds translocated from elsewhere [61] (p. 12a, plus annual reports 2016 onwards).

7.2. Predation

The DOC states that possums are significant predators of kea and kokako (*Callaeas wilsoni*) nests and also prey on bats [140]. However, it should be noted that:

- Stomach contents analysis of nearly 1900 possums from five studies showed a largely vegetarian diet topped up with invertebrates and no vertebrate remains. A subsequent study of 43 possums found remains of a greenfinch in one stomach [149];
- Three disparate observational studies concluded that mammalian predation of nests did not pose a threat to kea [150–152], in addition, despite substantial and repeated intrusion by humans on kea nests, very little evidence of predation was captured on video records [68,153] (pp. 15–18);
- Kokako nests were videoed under infrared light, and actual predation by the possums attracted to the nests was barely observed [154];
- Short-tailed bats were considered relatively safe from predators, being fast and agile, fiercely mobbing intruders and choosing winter roosts that were inaccessible [155].

7.3. Ineffective Ground-Based Management

Aerial poisoning has followed evidently ineffective management of rats. Three examples follow.

In the 2000s, aerial 1080 was used to quell bird-devastating rat plagues in forests that followed years of trapping for stoats [156] that apparently left rats with few of their main predator to control them. A warning from mustelid expert Dr. Carolyn King was seemingly not acted upon: "*Conservation management programmes already aiming to protect threatened species in beech forests from post-seedfall irruptions of stoats might need to be extended to include Ship Rats*" [157] (p. 143).

Management of the critically endangered Southern NZ Dotterel (*Anarhynchus obscurus obscurus*) on Rakiura has focused for decades on controlling cats at the birds' remote breeding ground on the Tin Range, despite a lack of evidence that cats were causing an observed decline in dotterel numbers [69]. Knowledge that the cats' main diet was rats [158] and a warning that rats also may need to be specifically controlled [159] did not result in this. Due to low dotterel numbers, the breeding area is to be aerially poisoned with 1080 in winter 2025 with the intention of killing rats, and cats through secondary poisoning, before the dotterels arrive in spring [22].

Ulva Island, an 'open sanctuary' for rare birds near Rakiura, was aerially poisoned with brodifacoum in 2011 and 2023 after a continuous risk of Norway rat invasion from nearby Rakiura was not controlled [51,160]. In 2022, the DOC's Island Eradication Advisory Group criticized the local DOC operation's performance over the years and expressed a lack of future confidence in it ([161], unpubl.) (Supplement Document S8). Nevertheless the 2023 poisoning went ahead and was associated with sharp declines in numbers of some bird species (South Island saddleback *Philesturnus carunculatus*, Stewart Island weka (*Gallirallus australis scott*) and Stewart Island robins *(Petroica australis rakiura)* (Mary Molloy, personal communication [162]. Rats reinvaded within months [160] and tests for brodifacoum in some marine life were still positive in June 2024 [163].

7.4. Eradication

Plans for eradication of a suite of mammals on NZ's main islands (Table 1) under the PF2050 strategy are expected to turn into 'roll-out' in 2030 [14]. Government documents state the "*pathway to Predator Free 2050*" includes "*sustained landscape-scale predator control which is crucial while we shift our sights to eradication…*" ([164] p. 37). "*Achieving PF2050 remains beyond our current capacity and capability . . . Tools like toxins, traps, genetic modifications, artificial intelligence, lures, detection and image classification, cameras, and detection dogs are all likely to play a part*" [14] (p. 19).

The eradication policy has been criticized in reviews by NZ ecologists. Drs. Wayne Linklater (from Victoria University) and Jamie Steer (from the Greater Wellington Regional Council) in 2018 [139], and independent scientists Drs. John Leathwick and Andrea Byrom in 2023 [55], described PF2050 as an unhelpful, poorly conceived distraction from conservation management that should, whilst recognizing predation as a threat, scientifically and systematically address the full range of threats to indigenous biota and ecosystems, such as ungulates and habitat loss.

Ecologists are warning of unpredictable, possibly negative effects, *if* eradication is achieved:

- "*Unintended consequences may include the eruption of unwanted herbivores and competing predators . . . and invertebrate biodiversity declines. Some effects will be unexpected and may be unrecoverable*" (Linklater & Steer, 2018) [139] (p. 2);
- "*Focusing management on just one driver of biodiversity loss not only ignores the effects of other pressures but also increases the likelihood of perverse outcomes such as favouring small*

subsets of indigenous taxa at the expense of or facilitating ecological release of other, potentially more damaging, invasive mammals" (Leathwick & Byrom, 2023) [55] p. 6);

- "*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*" (Norbury et al., 2024) [165] (p. v).

The PF2050 plans state "*No other country has ever attempted a multi-species eradication across its entire landmass. That means there's no manual to follow and the PF2050 community must learn by doing*" [14] (p. 10). The proponents are overlooking Chairman Mao's 'Four Pests' campaign which targeted four animals for elimination: rats, flies, mosquitoes, and sparrows. Without predation from sparrows, pests such as locusts thrived and became one of the causes of the Great Chinese Famine (1959 to 1961) [166].

NZ's smaller islands contain a wealth of biota, some endemic and some pseudoendemic (once also found on the main islands) as well as translocated rare species [167]. Removal of rodents does not necessarily restore the ecosystem to a pre-rodent state [11]. Eradications were found to be most likely to result in positive outcomes (for populations, communities or ecosystems) where anthropogenic disturbance was least and there were fewest introduced species [115,133], therefore such sites are highly valuable. Island eradications warrant well informed, targeted, technologically up-to-date management, as noted and discussed by Zavaleta [115] and Landcare Research ecologist Dr. Duane Peltzer and others in 2019 [6].

8. Discussion on Careful Management

8.1. Need for Change

It is clear from the foregoing that aerial poisons used to control mammals to conserve native biota are very broad spectrum, cause widespread suffering, create very high risks for species and ecological systems, and can be harmful, but the effects have not been well quantified.

Radical change in NZ's conservation management has been called for. Independent ecologists Leathwick & Byrom see new governance is needed to supersede the current socio-politically influenced, philanthropist-targeting, predation-based conservation management, which has failed to respond to ecologists' concerns [55]. Overhaul was called for long ago: in 2005 an independent, business-oriented review of the genesis and performance of the DOC pointed out that it had moved into unintended roles, with the expensive result that both the DOC and the Ministry for the Environment advised Government on conservation and environment issues ([168], unpubl.) (Supplement Document S9). The reviewers were critical of the DOC's lack of transparency, accountability, management skills and breadth of interest ([168], unpubl.).

Causes of loss of rare natural biota recorded by the DOC, apart from predation, have included poisoning, intensive monitoring, translocation, livestock (feral and farm) damage, neglect, drought, flooding, storms and road, hydro and other development [169].

A new, broad perspective is needed to address all threats, and scientific knowledge and methods must be instilled in management [55,91,139]. Leathwick and Byrom note that already an overhaul of conservation legislation is underway to strengthen protection of indigenous ecosystems and species, and that this needs to be accompanied by the establishment of shared governance [55]. They envision "*system-wide governance that brings together a full range of actors, centres Te Tiriti o Waitangi* (a treaty signed in 1840 between the British Crown and Māori chiefs), *shares decision-making power, facilitates stable conservation*

management through coordinated, long-term direction setting, and safeguards against undue influence from minority interest groups" [55] (p. 10).

8.2. Habitat Preservation

Seen as a priority conservation issue by ecologists [6,55,139], habitat loss, along with pollution and land development, has been a major cause of biodiversity loss in NZ [139]. As noted by King in 1984 "*one of the first basic rules of conservation biology: conservation of species is conservation of habitats. As C. Imboden put it, 'The continued survival of the full genetic heritage of any species is not possible outside the habitat to which it has become adapted as the result of long evolutionary processes'*" [147] (p. 137).

A framework based on spatial data analyzed with decision-making software has been developed by Dr. John Leathwick and others, to enable evidence-based prioritization of areas for ecosystem preservation and to quantitatively inform conservation management at all levels [170]. There is potential to increase the range of data used in the analysis, for instance adding distributional data for threatened species [170].

Sanctuaries have been promoted as a means of preserving species [11,55,91] however there seem to be many risks associated with them. Firstly, broad spectrum pest control to prepare the areas may have harmful effects on non-target biota (above), lessening the potential to create a natural environment. Secondly, the inhabitants are vulnerable. In fenced sanctuaries the inhabitants are naïve to predators [171], and some are flightless or poor fliers: in 2018, a single female stoat invaded Orokonui Sanctuary in Otago, eliminating the population of saddleback birds (*Philesturnus carunculatus*) [172]. Sanctuary inhabitants are also vulnerable to poor management—a whistleblower (one of a series) revealed that kiwi were dying at the privately owned Cape Sanctuary in 2016/17 [173]. The deaths were eventually officially attributed to dry conditions, predation and inadequate monitoring, however the inquiry revealed guests staying at luxury accommodation at the site paid to accompany kiwi handlers on 'health checks', hold the birds and be photographed with them. It appeared that one healthy kiwi chick was the subject of a 'health check' on 6 occasions over 11 days [174]. Another problem with sanctuaries is mice: in a reserve fenced to exclude mammals, increased mouse numbers apparently reduced numbers of wētā, caterpillars and other invertebrates, potentially having "*catastrophic*" effects. When the researchers eliminated the mice, unexpected things were noted: non-native earthworms seemed to move into the depleted ground faster than native earthworms and an extremely high number of beetles appeared in one area [175]. Another problem has been the arrival of large numbers of communal roosting birds such as starlings (*Sturnus vulgaris*) and sparrows (*Passer domesticus*) [176]. If sanctuaries provide model systems for understanding the outcomes of predator removal [6], there have been plenty of warnings of mayhem.

Associated with habitat preservation has been the translocation of animals for the protection and re-establishment of species [5,177]. However great care needs to be taken not to destroy genetic diversity through translocating unique populations [113]. Moreover, quarterly reports written by regional DOC managers ('Rare Bits' newsletters) from 1999 to 2004 [169] revealed a high rate of loss and mortality in translocated birds [178].

8.3. Ecological Knowledge

Gathering ecological information about mammalian species is vital for informing their management and needs to start in advance [1,6,55,115,132,139]. Associated biodiversity goals must be clear, and progress towards them monitored [55]. Independence of research providers from the influence of funders is highly desirable [55].

In a recent report from government-funded organization Landcare Research to the DOC, evaluating which of the proposed mammals should be included on its eradication

list, possums were stated to be "*one of the world's worst invasive species*" [165] (p. 2) although the citation trail did not yield any scientific evidence in support of this claim. Under '*Socio-political risks*' it was noted for hedgehogs there was a perception that they control garden pests, then this possibility was seemingly discounted on the basis of no evidence (it has not been studied). The assessment process, whilst preliminary, overlooked important evidence that hedgehogs may be beneficial to farmers in controlling the major pasture pests grass grub (*Costelytra zealandica*) and porina moth (*Wiseana cervinta*)—in a study on the Canterbury plains, it was estimated that the during the flight season of grass grubs the local hedgehogs had the potential to destroy between 10 and 40% of the adult population [179]. Also overlooked was the fact that rodent predation on wilding pine seeds is likely to be exerting significant control on these problem trees [180], and that Norway rats are major cleaners in urban environments: "*Offal and other animal by-products, edible flotsam along the waterfront, and sewage residues are cleaned up*" [4] (p. 188). Conservation scientists need to be vigilant against discrimination against non-native species, whereby ecologically they are perceived as doing little or no good [181].

Where restoration of ecosystems is attempted, keystone predators, along with plants and invertebrates, need to be considered; entire guilds of former species can be missing, and historical records are incomplete, therefore actual restoration is unlikely [11,182]. Once altered, the original habitat is unlikely to be recoverable [183]. Restoration is planned for Rakiura, but species have been lost—how will the extinct laughing owl (*Sceloglaux albifacies*) [184], for example, thought to be a ground-hunting predator [185], be replaced? Ecologist Professor Kevin Cianfaglione stresses that ecosystems are dynamic, not static, and should not be subjected to manipulation for the purpose of shaping them according to human desires [186]—personal interests should not influence ecological management [187]. Sixty years ago Rachael Carson wrote, "*The 'control of nature' is a phrase conceived in arrogance, born of the Neanderthal age of biology and philosophy, when it was supposed that nature exists for the convenience of man*" [188] (p. 154).

Regarding restoring the main islands of NZ, conservationist Bill Benfield wrote, "*. . . as the indigenous and exotic ecosystems have had in some cases nearly two centuries to integrate and become a homogenous whole, it illustrates the difficulty, in some cases the futility, of trying to separate and isolate for preservation the remnants as an indigenous biodiversity*" [8] (p. 109). It seems quite acceptable to ecologists that native and non-native can live together. Linklater and Steer wrote that in some environments, "*. . . lower intensity predator suppression, habitat protection and restoration, and prey refugia will sometimes better support threatened biodiversity*" [139] (p. 2). King and Forsyth (2021) stated, "*. . . mammals can be managed in only the highest priority areas. Over the rest of the country, the ancient, pre-human environment has been replaced by a new world . . .*" [1] (p. xxvii). They suggest that management outside priority sites might follow the definition of conservation proposed by ecologist Charles Elton: "*. . . some wise principle of co-existence between man and nature, even if it has to be a modified kind of man and a modified kind of nature*" [1] (p. xxxi).

8.4. Monitoring

Locating and intensive monitoring of bird nests, often in conjunction with attachment of harnesses holding telemetry equipment onto the birds, has been used by the DOC for decades, in predation-focused studies (e.g., [67,68,76]). However disturbing nesting birds is very likely to have a negative outcome [79]—in recognition of this it is illegal in the U.K. to intentionally disturb rare birds at this time [189].

Benign, scientific techniques for learning about ecology and threats to biota are needed to generate realistic results for management and new technology can assist with this. Artificial intelligence applied to wildlife camera-trapping networks should eventually

enable rapid and reliable estimates of animal density and abundance [190]. (Potentially, macro cameras could also be used to capture information on invertebrates.) Researchers from Victoria University at Wellington are applying AI to acoustic monitoring of birds and consider it should be possible to measure the activity of bird species at specific times and locations [191]. This technology could go a step further to provide more information, by monitoring specific calls (e.g., courtship, alarm calls).

A relatively benign technology (animal samples are needed) is stable isotope analysis, which was used to estimate the diet of stoats in alpine three of NZ's national parks—finding that mammals and insects comprised over 95% of the diet in two of the areas, whereas at the remaining site, where there was a lack of rat prey, birds and reptiles were also eaten [192].

8.5. Ground-Based Control

Traps, and poisons within bait stations, have been used extensively by the DOC to control small mammals and were reported on in the DOC's quarterly Rare Bits newsletters published 1999–2004 [169]. The observations revealed that when mammals were controlled, intensive, constant, simultaneous control of stoats, rats and cats was necessary to prevent native species loss; trapping to just remove stoats had been followed by rat plagues; trapping was effective for catching multiple pest species (including stoats, ferrets, weasels, rats, cats, possums, hedgehogs and mice); and some traps (leghold, Elliot, Easiset and Fenn) harmed native species including birds, lizards and giant weta (*Deinacrida* spp.) [193]. Trapping appeared to become less effective in catching stoats when mice were very abundant, therefore a variety of control techniques was recommended (including using dogs to find breeding dens) [194]. A rat plague was successfully quelled the Eglinton Valley, using a succession of different poisons in closely spaced bait stations [156].

In 2010, Landcare Research toxicologist Dr. Penny Fisher warned against the use of brodifacoum in bait stations due to secondary poisoning and residues in non-target wildlife, stating that "*large-scale, ongoing field applications of brodifacoum in bait stations in New Zealand are likely to be contaminating a range of non-target mammals, birds and invertebrates. For some species this could mean an as-yet unknown but potentially significant mortality through accumulation of liver residues*" [42] (p. vi). A list of causes of death of kiwi in Northland over 20 years, provided by the DOC, showed that 53 (of 740 dead kiwi) had been tested for anticoagulants such as brodifacoum, and 38% of those were positive (however the cause of death was not listed as 'pesticide') [103].

The possibilities for efficient, targeted, humane ground-based control of small mammals have dramatically improved this decade. Devices that can be bought 'off the shelf' for instant killing of possums and rats include self-resetting gas-powered kill traps, which can automatically reset up to 24 times [195]. Smart kill traps, which use artificial intelligence to discriminate between animals and only activate for specific targets, are also available—solar powered, with automated reporting [196].

Control of ungulates (mainly deer), aided by helicopters began in the 1960s and became very successful commercially, supplying venison and live animals for farms. In the 1970s there was an annual harvest of 130,000 deer; the industry reduced deer numbers and some dramatic changes in vegetation were observed as a result [1,197]. The commercial harvest declined in the 1990s and in the 2020s a small number of helicopter operators carrying out commercial venison recovery remained, with other control of deer numbers coming from recreational hunting, shooting by the DOC and 1080 poison (usually incidentally rather than targeted, with 'bykill' of deer ranging from nearly zero to nearly 100%) [197]. Although recreational hunters have a significant impact (estimated harvest of 135,000 deer in 2012), the density of some deer species, such as red and fallow deer, are considered to have been increasing in many areas [198] and overall numbers of all the major ungulate

species are much higher than in the 1980s [1,199]. Some hunter groups are providing management of deer herds in collaboration with the DOC and others. For example the Sika Foundation manages the Sika deer (*Cervus nippon*) herd for the benefit of both hunters and environmental protection, and aims to effectively engage in collaborative management with hunters, the Game Animal Council (established in 2013, to represent the interests of the hunting sector and improve the management of hunting resources, whilst contributing to desired conservation outcomes [200]), the DOC, local Iwi (Māori), landowners, and other stakeholders [201].

Where informed management effectively controls small, introduced mammals with smart traps and hunting, and ungulates by hunting, these methods can be used to mimic natural predation pressure, potentially allowing management without triggering unwanted ecological effects that may harm native biota.

8.6. Animal Welfare

Ethicist Margodt wrote, "*Species conservation does not offer a carte blanche justification for the use of poisons . . . Humanity has become way more sensitive to animal suffering and rightly so. Conserving New Zealand's native species is of major importance, but this needs to be done in a compassionate and ethical way*" [91] (p. 13). Dr. Emily Major pointed out in her PhD that a compassionate approach not only benefits the animals being managed, but human-to-human relationships through the promotion of empathy [202]. Bekoff reminds conservation managers that animals are "*not unfeeling objects with whom we can do whatever we like. Each and every individual cares about how they're treated*" [90] (p. 1). He advises, "*Simply put, conservation is a moral pursuit and demands clear ethical guidelines*" [203] (p. 1). He suggests NZ follows the principles of Compassionate Conservation: First Do No harm, Individuals Matter, Valuing All Wildlife and Peaceful Coexistence" [203].

8.7. Governance

Leathwick & Byrom point out that historically, shared, participatory governance has been more successful in achieving positive environmental outcomes than state-led governance alone [55]. Existing groups such as the Sika Foundation who are already engaging with diverse stakeholders in deer management will have valuable experience to tap into [201]. The amount of money used in conservation is vast: $400 million NZD was appropriated for 2025/26 for the DOC's management of 'natural heritage' plus 'conservation in the community' [204]. Leathwick and Byrom consider there is doubt that conservation resources are currently being used cost-effectively [55].

Astute governance will find opportunities for commercial exploitation to offset control costs. Wild animals apart from deer have been exploited commercially in the past—for instance large numbers of rabbits were exported as frozen carcasses (6.5 million in 1900) and skins (20 million in 1924) [205]. At the peak of the possum fur industry in 1981, 3.2 million skins were exported [206].

Governance of conservation management needs to reach deep into the community to ensure efforts at grass roots level do not cause ecological imbalance, or traumatize humans or animals. Margodt points out that young people who have witnessed animal abuse in community conservation activities can be haunted for years [91]. Rather, young people could be exposed to respectful attitudes towards animals and nature, based upon compassion and empathy [91] as well as knowledgeable appreciation (for example, in an investigation of the learning ability of possums (using successive discrimination reversal), one-trial learning was observed on several occasions, and overall scores appeared "*comparable with, if not superior to, those reported in earlier studies for some rodents, carnivores, and*

primates" [207] (p. 1). Dr. Jane Goodall observed that the use of the word 'pest' invites discrimination [90] (p. 1).

The range of potential stakeholders involved in an overhauled conservation system is vast and includes highly divergent attitudes including two extremes of animal lover—those who love all, and those who only love the native ones. Stakeholders also include the environment and its biota [91], whose interests are looked after by the principles of Compassionate Conservation.

9. Conclusions

Landscape aerial poisoning to kill mammals to conserve NZ's native biota causes widespread suffering and can be harmful, but the harms have not been well quantified, and the poisoning is increasing. Hippocrates's principle, "*First, do no harm*", needs to be applied, urgently.

An overhaul of NZ's conservation management has been called for by leading NZ and international scientists, whereby the current focus on killing certain mammals is exchanged for a new conservation framework that embraces all threats, is informed by ecological science, ethical, and inclusive of all stakeholders. The efforts of the various conservation players can be aided by efficient technology, to carefully observe and conserve what is left.

The needs for habitat protection, and non-intervention, have been overlooked. As stated over 40 years ago by King: "*The hardy species are the ones that have survived on the main islands for at least a hundred years in company with the whole range of predators and other habitat changes, and therefore are able to come to some sort of terms with them . . . What conditions do they require? Simply to be left alone in their natural habitat, and enough of it. In the long run, the continued survival of any species genotype is impossible outside the habitat to which it is adapted: conservation of species and of habitat are the same thing*" [147] (p. 183).

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/conservation5030047/s1, Figure S1: Stills from video documentation after aerial distribution of 32,000 kg of cereal pellets containing 1080 in Pirongia State Forest, Waikato Region, 2014: (a) Female brushtail possum (*Trichosurus vulpecula*) found dead with young still clinging to her dead body; (b) Another female possum carcass with young attempting to nurse from dead mother, Figure S2: Three dead red deer (*Cervus elaphus*) documented the day following aerial broadcast of 1080, June 2010, Westland. Bloodshot eyes, blood-stained foam from the mouth, and evidence of hours of thrashing are typical signs of 1080 poisoning in this species (Clyde Graf, personal communication [138]), Document S1: Contract Wild Animal Control New Zealand, Application Form for Predator Control in the Wet Jacket Operational Area, 2019, Document S2: Pollard, J., Evidence of breaches of the HSNO Act in the 2007 assessment of 1080 poison, Document S3: Whiting-O'Keefe, Q., Whiting-O'Keefe, P., Aerial monofluoroacetate in New Zealand's forests—An appraisal of the scientific evidence(public submission), Document S4: Pollard, J., Quotes regarding the variability in toxicity from the ERMA reassessment of 1080, Document S5: Pollard, J., Quotes regarding unexpected chemical behaviour from the ERMA reassessment of 1080, Document S6: Pollard, J., A scientific evaluation of the Parliamentary Commissioner for the Environment's views on 1080, Document S7: Department of Conservation. Response to a Request Under the Official Information Act (1982) 18 March 2022, Document S8: Department of Conservation Island Eradication Advisory Group, Letter to Stephen Horn, Department of Conservation, 22 December 2022, headed 'Ulva comments from IAE discussion, December 2022.', Document S9: Centre for Resource Management Studies. The role of the Department of Conservation and the need for change.

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Conflicts of Interest: In 2018 the author established The Wild Treat Company Limited which uses culled wild mammals for manufacturing domestic pet treats. This provides ethically responsible pest control. It was created to make progress after the first 11 years of voluntary research and publishing on aerial poisoning and management alternatives ([208], unpubl.) gained little traction.

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